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How much energy do we need to live decently?

Clémence Briodeau*, Corinne Chaton**

ABSTRACT

To reduce fuel poverty and work towards a fair energy transition, it is important to know the 'essential goods basket' of each household. This is then used to determine the income needed to live decently, taking prices into account. One component of this essential basket is a decent level of energy for housing. The main objective of this study is to estimate, using French public data, the minimum quantity of energy that would enable each household to meet its basic needs in its home, depending on its characteristics, its home and its location. Estimating minimum energy levels obviously reveals significant differences depending on the thermal quality of the dwelling (measured by an EPC rating). The type of dwelling and its surface area also have an impact. Household composition, on the other hand, does not appear to be statistically significant.

The authors are solely responsible for this work with no engagement from the institutions to which they belong.

Keywords: Energy, housing, reference budgets

JEL: D12, Q41

1. INTRODUCTION

According to Eurostat, in France, 12.1% of households were not able to keep home adequately warm in 2023, compared with 10.7% (6%) in 2022 (2021). 26% of French people say they suffered from the cold during the winter of 2022-2023, 42% of them for financial reasons (Observatoire National de la Précarité Energétique (ONPE), 2024). More and more consumers say that they are limiting the heating in their homes to avoid excessive energy bills (Le médiateur national de l'énergie, 2023).¹ However, French households have benefited from exceptional measures introduced by the government in 2022 and 2023 (e.g. tariff shield for electricity and natural gas, exceptional energy voucher). The end of this financial support makes the situation even more difficult for the most modest households, particularly those living in poorly insulated homes. The latter are also more affected by energy transition policies, which do not have the same impact on all areas and all social categories, and create risks of inequality. To prevent these households from falling into fuel poverty² and to work towards a fair transition, we believe it is necessary to introduce equity considerations based on baskets of goods needed to live decently.

In order to define the income enabling a specific household to acquire its *essential basket*, we determine in this study the minimum energy levels for housing necessary for households to live decently. This basket of goods necessary for a decent standard of living covers the energy needed by a

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¹Le médiateur national de l'énergie is the National Energy Ombudsman.

²Fuel poverty is defined as follows in French legislation: "a household that has difficulties obtaining the necessary energy to satisfy their basic needs due to the inadequacy of their resources or their living conditions is in fuel poverty under this Act" (Grenelle II Act of 12 July 2010).

household to meet its basic needs in its home, as well as food, housing, transport, health, etc. Many authors have studied the determinants of energy consumption in the residential sector. For example, [Brounen et al. \(2012\)](#) deduce from their analysis based on a sample of over 300,000 Dutch households that residential natural gas consumption is mainly determined by the structural characteristics of the dwelling, while electricity consumption varies more directly according to household composition. We can also mention [Haas \(1997\)](#); [Guo et al. \(2018\)](#); [Lee and Song \(2022\)](#) or for a study on France [Belaïd and Garcia \(2016\)](#). But to our knowledge, few authors have taken an interest in determining the level of energy needed to live comfortably in one's home. Of course, as with energy consumption, the composition of the household is likely to have an impact on this minimum energy level, but intuitively this level should depend mainly on the characteristics of the home, in particular its surface area and its thermal quality, as measured by the energy performance diagnostic, as well as its location. The French energy performance diagnostic³ provides an Energy Performance Certificate (EPC) rating, i.e., information on the energy consumption and greenhouse gas emissions of a dwelling, and estimates the annual energy bill of the household living in the dwelling.⁴

Knowledge of this minimum energy level is necessary both because it forms part of the basket of essential goods and because its weight in the calculation of 'Reference Budgets' (or Standard Budget, or Minimum Income Standard) can be very significant. The term *reference budgets* is used to determine the income needed to purchase a set of goods and services essential for a decent life. As [Fisher \(2007\)](#) points out, "A 'standard budget' is a list of goods and services that a family of a specified size and composition—and sometimes of a specified social class or occupational group—would need to live at a designated level of well-being, together with the estimated monthly or annual costs of those goods and services." These reference budgets, originating in the family budget as a means of analysing the standard of living, seem to have emerged in Great Britain in the 17th century ([Deeming, 2010](#)). They are an indicator of minimum income on which public policies to combat poverty are based. By giving minimum levels, they could also quantify the notion of sobriety. Knowing the minimum energy needs of households in this basket makes it easier to quantify the energy vouchers that can be distributed.⁵ This knowledge can also form the basis of insurance contracts against fuel poverty, as proposed by [Alasseur et al. \(2022\)](#); [Chaton and Guillerminet \(2023\)](#) and of fair differentiated pricing.

As [Preuße \(2012\)](#) points out, there are two approaches to calculating *reference budgets*. In the first approach, experts and/or representatives of the population jointly determine the goods and services needed and their quantity. In France, the report by [Gilles et al. \(2014\)](#) produced for the French National Observatory on Poverty and Social Exclusion (ONPES) is one example. The second approach is based on statistical data obtained from national surveys. To calculate the minimum energy levels, we use the second approach.

In France, several studies have quantified *reference budgets* for a decent standard of living. Firstly, the DREES⁶ Opinion Barometer provides information on French people's views on minimum social benefits, and in particular on the minimum individual monthly amount needed to live on. Thus, "on average in 2019, the French believe that a single person should have at least €1,712 per month to live on" ([Buisson et al., 2020](#); [Lardeux and Pirus, 2020](#)). This amount is significantly higher than the 'Revenu de solidarité active', RSA⁷ (€560) and even the French minimum wage, SMIC (€1,204). It has been rising steadily since 2008, and was €1,760 in 2018 and €1,570 in 2017. It varies according

³In French: Diagnostic de performance énergétique, DPE.

⁴Specifically, it reflects the consumption in primary energy as expressed in kWh_{pe} per m² and per year for heating, domestic hot water, and cooling. The primary energy accounts both the final energy, that is, the energy used by a house (natural gas, electricity, heating oil, etc) plus all the energy needed to extract, transport, store, and produce them. Depending on the estimated level of energy consumption, a label score is assigned from A (most efficient) to G (least efficient).

⁵The energy voucher is a public financial aid scheme in France, created by the Energy Transition Act of 17 August 2015, designed to help low-income households pay their energy bills. It replaces the social tariffs for electricity and natural gas.

⁶The Direction de la recherche, des études, de l'évaluation et des statistiques (Drees) is a department of the French central administration of the Ministries of Health and Social Affairs.

⁷The RSA is a minimum income for people with no resources, which varies according to the composition of the household.

to standard of living (€1,580 per month for the lowest 20% of French people, €1,870 for the highest 20%) and age (€1,647 for those aged 30 and under, €1,727 for those aged over 30). Closer to our study, in 2012 the French National Observatory on Poverty and Social Exclusion (ONPES) launched a call for projects to quantify a decent minimum income by household category. The result was a report providing initial estimates of reference budgets in France (ONPES, 2014-2015). A participatory approach was adopted to draw up these budgets. Groups of citizens from different socio-demographic categories were invited to discuss and identify the goods and services essential for participation in social life, drawing on expert advice to reach a consensus. The needs covered were food, housing, transport, health, leisure and culture. According to the citizens' groups, "*the minimum monthly reference budgets for effective participation in social life range, depending on family configurations, from 1,424 euros (for a single active person) to 3,284 euros (for a couple with two children)*". These estimates are based on the assumption that households live in social housing. When they live in private accommodation, the reference budgets are between €1,571 and €3,515. The largest item is housing, which accounts for 33% of the budget of a single person in employment and 22% of that of a couple with two children. Gilles et al. (2014) break down the 'Housing' item into several parts, one of which is the subject of our study, namely energy expenditure. They estimate in 2013–2014, the financial amount needed to meet the energy needs of a home for 1) a single person: 78 euros per month, 2) a working couple without children: 105 euros per month, 3) a retired couple: 107 euros per month, 4) a single-parent family: 116 euros per month and 5) a couple with two children: 135 euros per month. Unfortunately, these estimates are based on household expenditure in two medium-sized French cities, Tours and Dijon, where the survey was carried out. As a result, they should not be used to calibrate energy policies throughout France. They do not consider the impact of location, and in particular climatic region, on energy expenditure. In addition, the surface area and thermal quality of homes, which have a major impact on the energy needs of households for their homes, are not taken into account.

More recently, the Conseil national des politiques de lutte contre la pauvreté et l'exclusion sociale (CNLE)⁸ updated and supplemented the study by Gilles et al. (2014). The report of Lelièvre (2022) extends the geographical scope to include rural municipalities and the Greater Paris metropolitan area. For 2018, the reference budgets are estimated at between €1,363 and €3,824 in rural areas, depending on family configuration and housing occupation status. These estimates range from €1,691 to €4,459 in the Greater Paris area. For a single active person renting social housing, it is estimated at €1,419 in rural areas, compared with €1,863 in the Paris region. These differences can be explained by the cost of services, infrastructure and housing, which vary considerably depending on the geographical area. For example, people living in rural areas have higher transport costs due to the lack of efficient public transport, while those living in the Paris conurbation face very high housing costs. Although the CNLE provides reference monthly budgets for housing (389, 487 and 623 euros respectively in rural areas, medium-sized towns and the Paris conurbation, for a single active person renting social housing), the breakdown of these budgets, and in particular energy costs, are no longer detailed in this study. On the one hand, energy for housing can represent a significant proportion of a household's compulsory expenditure. On the other hand, the variation in this cost can be significant, even over the course of a year, as has been the case since autumn 2021 in European countries (see, for example, Davis et al. (2022); Bolton (2024); Einolander et al. (2024)). Knowing how much energy a household needs to live comfortably (i.e. the minimum energy level) makes it easier to factor variations in energy prices into *reference budgets*.

Chaton and Guillerminet (2023) estimate the minimum energy levels. They propose a measure to cover households against the risk of fuel poverty: an insurance policy guaranteeing households this minimum level. To estimate this decent amount of energy, they use data from INSEE's Statistics on Resources and Living Conditions (SRCV) 2019 survey, focusing on households living in

⁸CNLE is the National Council for Policies to Combat Poverty and Social Exclusion.

an all-electric dwelling (heating, hot water, cooking).⁹ Based on declared energy expenditure, and assuming that electricity is paid for at EDF's Blue peak/off-peak tariff,¹⁰ they deduce the amount of electricity consumed by each household. Once converted into a quantity of primary energy,¹¹ this is used to determine the EPC rating of homes. Finally, limiting themselves to a sample of households considered as '*strained households*', i.e. households that only have the financial capacity to consume the essential goods basket, they calculate the average primary energy consumption per m² and per year for each EPC class and then determine the minimum energy levels required by each household. However, the methodology adopted by these authors can only be used for dwellings with a single energy source (electricity).

Our aim is to determine for each French household the level of energy they need to live comfortably in their home. We define and quantify the notion of *decent* and we propose a method to overcome the lack of data. This lack mainly concerns current and past data on dwellings and their occupants in France, which are needed to define the energy needs of a given household. This lack was confirmed by the supreme body for auditing the use of public funds in France (Cour des Comptes, Referral S2022-0931 of May 12, 2022)

As [Chaton and Guillerminet \(2023\)](#), to define minimum energy levels, we use data from the SRCV survey. But, the information in this survey is not sufficient to assign an EPC rating to the homes of all the households in the survey. However, on the one hand, the EPC rating of the dwelling has a major impact on the energy needs of households for their homes and, on the other hand, as [Merly-Alpa \(2023\)](#) points out, "*Despite its limitations, the EPC is an indicator which can be used to compile statistics on the state of the housing stock.*" In order to assign an EPC rating to each property in the SRCV database (in section 3), we also use the ADEME's EPC database.¹² These databases are presented in section 2. In section 4, we look at the determinants of housing-related energy expenditure and estimate the gain (on bills) of an improvement in the energy efficiency of the home (improvement in the EPC rating). In section 5, we estimate the decent energy levels of households for their homes. Due to the lack of information, we have limited the analysis to all-electric dwellings and those with natural gas and electricity.¹³ Section 6 concludes.

2. DATA AND DESCRIPTIVE STATISTICS

2.1 INSEE's Statistics on Resources and Living Conditions (SRCV) survey

SRCV is the French component of the European Union – Statistics on Income and Living Conditions (EU – SILC). SRCV is an annual panel survey that provides a detailed overview of household income, financial situation and living conditions. It also takes into account expenditure on housing, and in particular declarations of the annual amounts spent on electricity, natural gas and other end-use energy sources on heating or domestic hot water, which are the focus of interest here. The survey covers all 'ordinary households'¹⁴ living in mainland France.

As mentioned in the introduction, we assign an EPC rating to each dwelling in the SRCV database. The accuracy of these attributions cannot be verified directly. However, it is possible to compare the distribution of the EPC ratings obtained with the estimate of the state of the housing

⁹INSEE i.e. Institut national de la statistique et des études économiques, is the National Institute of Statistics and Economic Studies in France.

¹⁰Under the Peak/Off-peak option, unlike the Base option, the price per kWh varies according to the time of day.

¹¹The quantity of primary energy is obtained by applying a conversion factor from final energy to primary energy. For electricity in 2019, this factor is 2.58.

¹²ADEME is the French Agency for Ecological Transition.

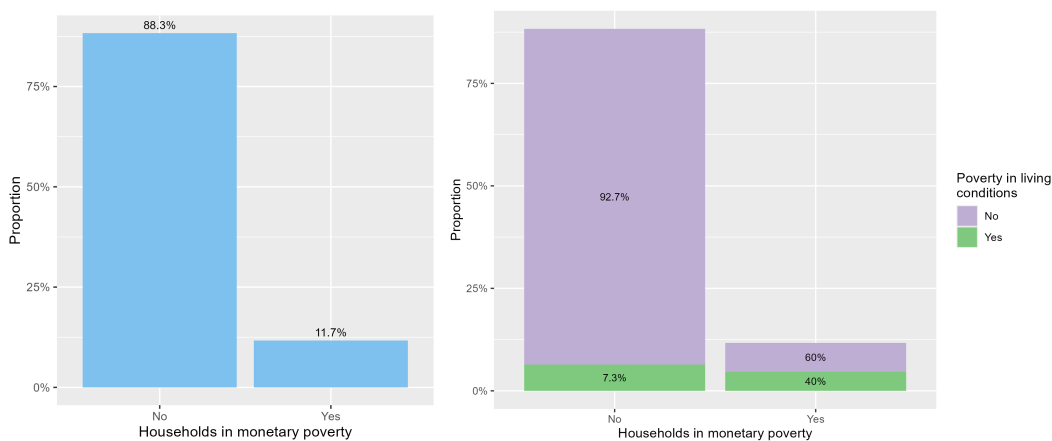
¹³The SRCV database aggregates expenditure on other energy sources.

¹⁴This excludes households living in collective accommodation (hostels, prisons, hospitals, etc.), people living in mobile homes (e.g. bargemen) and the homeless.

stock by energy efficiency score at 1 January 2018 given by Merly-Alpa et al. (2020). An update for 2022 has been provided by Le Saout et al. (2022), but we cannot use data from more recent vintages of SRCV. This is because the distinction between electricity and natural gas was removed from 2020. Since 2021, electricity, natural gas and heating bills have been included in the cost of housing. We have therefore made the (constrained) choice to use data from the 2017 wave of the SRCV (SRCV2017). In 2017, 11,068 households responded to the survey.

SRCV data can be used to calculate some statistics on poverty in France in 2017. 11.7% of households are at risk of monetary/income poverty, i.e. their **standard of living** is below the poverty threshold, set at 60% of the median standard of living. Poverty is not exclusive to these households. In fact, some people are forced to go without or give up consumer goods, services or equipment for financial reasons, even though their household standard of living is higher than the median standard of living. To understand the phenomenon of poverty in its entirety, we need to compare the notion of monetary poverty with that of poverty in living conditions.¹⁵ Thus, among households in monetary poverty, 40% are also poor in terms of living conditions; this is also the case for 7.3% of households that are not poor in monetary terms (FIGURE 1). These households with precarious living conditions are proportionately more numerous in Île-de-France, the Mediterranean and the North (FIGURE 11 in Appendix A). They mainly rent (64%), almost half live in a house (compared with 67% of the non-poor), and half also have difficulty heating their home (compared with only 18% of the non-poor). 44% of them are single people, 21% single-parent families, 10% couples without children and 23% couples with children; these rates are 33%, 7%, 30% and 28% respectively for households not experiencing poverty in living conditions (FIGURE 12 in Appendix A).

Figure 1: Households in poverty in 2017



Note: The figure on the left shows the percentage of households in monetary poverty in 2017. The figure on the right compares income poverty and poverty in living conditions. Thus, 7.3% of households that are not poor in monetary terms are poor in terms of living standards.

Source: SRCV2017.

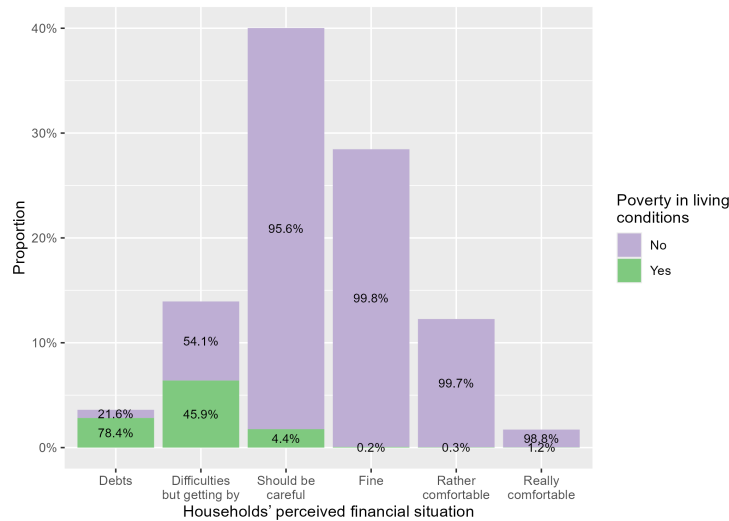
Beyond these two indicators, it is also interesting to look at how households perceive their current financial situation.¹⁶ In particular, some households that are not poor in terms of living conditions say that they are having difficulties but that they are getting by (54.1%), or that everything is fine but that they have to be careful (95.6%). We can therefore assume that they are saturating their budgetary constraints and that their financial resources only allow them to consume the minimum

¹⁵A household is poor in living conditions according to the INSEE definition when it accumulates at least 8 deprivations or difficulties out of 27 relating to insufficient resources, late payments, consumption restrictions and housing difficulties (See Appendix A).

¹⁶Question code: NIVACTB.

amount of energy and the minimum amount of composite goods necessary to live decently. We call them ‘strained’ households. Like [Chaton and Guillerminet \(2023\)](#), we consider that the budget of these households is only the reference budget. We therefore assume that their energy expenditure on housing corresponds to the cost of their decent level of energy. Consequently, to determine decent energy levels, we consider only the ‘strained’ households. There are 4,232 of them.

Figure 2: Households’ perceived financial situation and poverty in living conditions



Note:

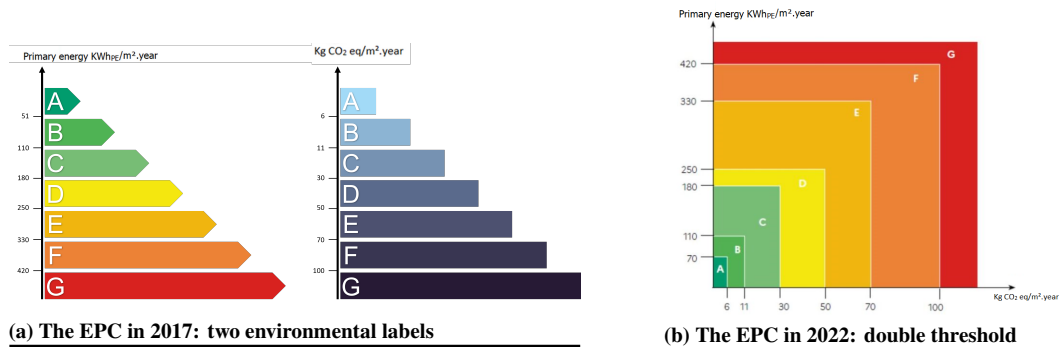
Source: SRCV2017

As indicated in the introduction, these minimum energy levels depend mainly on the characteristics of the home, and in particular its thermal quality, which can be assessed using the energy performance diagnosis summarised by an EPC rating. Introduced in France in 2006, this diagnostic provides information on the energy performance of a home or building, by assessing its primary energy consumption and greenhouse gas (GHG) emissions. It is therefore essential for explaining energy expenditure and quantifying the energy needed to live decently. However, the SRCV survey does not provide any information on the EPC rating of the dwelling in which the household lives. It is therefore important to be able to estimate the energy efficiency score for the dwellings of each household in the SRCV database.

2.2 Energy performance Certificates, EPC

Since 2013, all EPCs carried out in mainland France have been collected by Ademe. The EPC calculation method underwent major changes in 2021, in order to make it more reliable. The ‘on-bill’ calculation method, which assessed the energy consumption of certain homes on the basis of past bills, has been removed and replaced by the ‘3CL’ method (calculating the theoretical energy consumption of homes). This method is based solely on the physical characteristics of the dwelling (building, insulation quality, type of windows, heating system) and is based on standardised uses. It makes the EPC enforceable.¹⁷ The thresholds defining the various energy performance labels have also been revised, and are now calculated on the basis of two factors: primary energy and GHG emissions, in order to include a climate component (FIGURES 3a and 3b). The 2021 version of the EPC gives an estimate of the energy bill.

¹⁷A seller or landlord is now held responsible for any errors that could harm a future buyer or tenant. The latter therefore has the right to take the necessary legal action. The EPC is no longer merely informative. It is now legally binding.

Figure 3: EPC band in 2017 and 2022

Note: On the left, the energy label, on the right, the climate label.

Note: If the dwelling emits 35 (28) kg of CO₂/m².year and its energy consumption is 115 KWh/m².year, then its EPC score is D (C).

As changes have been made to the calculation of the EPC up to October 2021, we have chosen to select from the Ademe database all the EPCs drawn up in 2022 in versions 2.1, 2.2 and 2.3, i.e. a total of 908,007 dwellings.¹⁸ As the number of observations is already sufficient, in the interests of simplification and reducing processing times, we are not using the EPCs drawn up in 2023. It is also important to note that the Ademe's EPC database is not representative of the entire housing stock, as EPCs are only produced for sales and new rentals. It cannot therefore be used directly to describe the state of the housing stock in terms of energy consumption and GHG emissions. It can, however, be used to predict EPC ratings.

A number of housing characteristics are present in both the SRCV database and Ademe's EPC database. This is the case for the type of dwelling (flat or house), the surface area, the date of construction, but also the ZEAT¹⁹ and the size of the urban unit (these last two variables are deduced from the commune code in the EPC database). There is no geographical level finer than the ZEAT in the SRCV database. A comparison of their distributions is presented in Appendix A (FIGURE 13). In particular, the proportion of dwellings built before 1949 is much higher in the EPC database than in the SRCV database. There is also a greater proportion of flats and therefore smaller dwellings, whereas the SRCV contains more houses. This is partly explained by the under-representation of dwellings in rural municipalities in the Ademe database and the over-representation of those located in large conurbations; even though, overall, the distributions of EPCs and urban unit sizes are relatively close.

Both databases also provide information on annual energy bills. In SRCV, households are asked about the annual amounts spent on electricity, natural gas and other heating or domestic hot water (DHW) costs. In the EPC database, an energy balance sheet is provided, showing final energy consumption, GHG emissions and, above all, the estimated costs for standard use of each energy consumed: cost of heating, cost of DHW and total cost for the five uses (DHW, heating, air conditioning, lighting and auxiliaries). It is therefore possible to compare the bills in the two databases, after correcting for price variations between 2017 and 2022 (FIGURE 14 and TABLE 6 in Appendix A). The distributions are broadly similar, although annual expenditure on electricity is higher in SRCV than in the EPC database, as is expenditure on heating and DHW (excluding electricity and natural gas). Expenditure on natural gas is lower in the SRCV survey than in the EPC database.

¹⁸Ademe has informed us that from version 2.1, introduced in December 2021, the EPCs are of sufficient quality to be analysed in detail.

¹⁹Zone d'études et d'aménagement du territoire i.e. survey zone and national planning.

Using these two databases and their common variables, the aim is to assign an EPC rating to the dwellings of households surveyed in SRCV. The method used to achieve this is presented in the next section. The paucity of data available in the residential sector on a household's energy consumption, its characteristics and those of its dwelling, as well as a number of quality problems in public databases, makes this step difficult. There is, of course, the “Enquête Nationale Logements” (French Housing Survey), which describes the housing conditions of households and their housing expenditure. However, this survey is carried out very infrequently, so the data is old: the penultimate edition dates from 2013, and the next one is in progress (2023-2024). The latest edition was carried out in 2019-2021, but collection was interrupted twice because of the Covid epidemic, it was completed by telephone, and the results made available at the time our study was carried out correspond to a provisional version: we therefore prefer not to use it.

3. AN EPC SCORE FOR EACH PRIMARY RESIDENCE

Using Ademe's EPC database, we assign an EPC rating to the dwellings of households in SRCV: this is an essential stage in our study, since energy expenditure and consumption depend on the EPC rating, a proxy for the thermal quality of the dwelling. Several approaches have been developed in the literature to predict a dwelling's EPC score. Grossouvre et al. (2023) use the k nearest neighbours (KNN) model to predict the EPC rating at the address in the Imope database.²⁰ The KNN model enables them to estimate the energy performance of a building using the known performance of similar buildings, whether geographically, in terms of structure or the socio-economic situation of the occupants/owners. Ben Rejeb-Mzah et al. (2023) seek to predict EPCs for French dwellings not included in the Ademe database. They first use a model that takes the average energy performance of the nearest dwellings as a proxy. They then test classification algorithms using additional variables (physical and technical characteristics of the buildings) available in the notaries' database. However, all these methodologies rely on information that is not available in the SRCV survey (in particular the address), which is why we are proposing an approach adapted to the data available to us.

3.1 Preliminary checks and corrections

The main aim is to take account of changes in the thresholds for calculating energy labels between 2017 and 2022 (FIGURES 3a and 3b). This is necessary in order to be able to compare the state of the housing stock that we obtain with our pseudo-matching and the actual state in 2017 (given by Merly-Alpa et al. (2020)). In the EPC 2022 database, we therefore recalculate the energy label that dwellings would have obtained in 2017, based on their primary energy consumption in kWh per m² per year and the old thresholds.

Annual energy bills, which are included in both the SRCV survey and the EPC database, can help to forecast EPCs. However, since the revision of the EPC and the standardisation of its calculation method, these annual energy bills are estimated for standard use for the Ademe data.²¹ They can therefore fluctuate according to the use of the dwelling, the weather, the number of occupants and lifestyle habits. In contrast, the households surveyed in SRCV declare their 'real' expenditure on electricity, natural gas, heating and DHW. The comparison may therefore be subject to several biases. First of all, there is a risk of climate bias, if 2017 was warmer or colder than average, but the data on unified degree-days (UDD)²² published by the French Statistical Data and Studies Department

²⁰IMOPE is a French reference database of buildings at national level.

²¹Conventionally, they are given for a heating temperature of 19°C, reduced to 16°C at night or if the home is empty, air conditioning set at 28°C (if there is air conditioning), and hot water consumption of 132 litres per day.

²²The French Statistical Data and Studies Department calculates the average extreme temperatures on a given day $T = (T_{\text{minimum}} + T_{\text{maximum}})/2$. The number of degree-days for that day is equal to: $17 - T$ if $T < 17^\circ\text{C}$, 0 otherwise. The UDD corresponds to the sum of the degree-days for all days from October to May.

(SDES) reassures us on this point: the rigour index, which corresponds to the ratio between the UDD in 2017 and the average UDD over the reference period, is close to 1.²³ We must also take into account the existence of households that restrict their consumption and could therefore have lower energy bills than those corresponding to standard use. Their home could then be given a better EPC rating than it actually is. There are many such households. In fact, according to the Médiateur National de l’Energie (National Energy Ombudsman), in 2016 (2017), 34% (30%) of households say they have restricted heating at home to avoid excessive bills (ONPE, 2017, 2018).²⁴ We identify these households in SRCV, using the binary variable TEMP: ‘Financial means to maintain the dwelling at the right temperature’.²⁵ We then estimate the total energy bill as a function of the characteristics of the dwelling, the household and the variable TEMP, a proxy for any energy restriction. According to the models tested, we always obtain a non-significant or positive coefficient for households with more limited financial means. This is explained by the fact that they more often live in “leaky home”, i.e. one that is very energy-intensive, and that we do not have enough variables in SRCV to capture the differences between dwellings. We cannot therefore correct the bills of restricted households solely on the basis of SRCV data.

3.2 Multinomial logistic regression

We use a multinomial logistic regression model to predict the EPC scores of households’ dwellings in SRCV. This is a classification problem in which the dependent variable, the energy performance label, takes six forms: A–B, C, D, E, F and G.²⁶ Based on the methodology used by Le Saout et al. (2022), six distinct models according to the type of energy consumed by the household in its dwelling are considered: (1) electricity alone, (2) electricity and natural gas, (3) use of another energy source for heating and DHW, and according to the type of dwelling: (a) flat and (b) house. The explanatory variables used by the model are those present in both the EPC database and the SRCV survey: surface area, ZEAT, size of urban unit and annual bills for each energy consumed.²⁷

Let us denote y_i the EPC label of the dwelling i , $\pi_i^{(0)}$ the probability that the dwelling i has an EPC rating of A–B (the reference modality) and $\pi_i^{(d)}$ the probability that it has a rating of d ($d = C, D, E, F, G$). We determine the relationship between these probabilities and the p explanatory variables X_1, X_2, \dots, X_p , using the following multinomial logistic regression model:

$$\log \left(\frac{\pi_i^{(d)}}{\pi_i^{(0)}} \right) = \beta_0^{(d)} + \beta_1^{(d)} x_{1i} + \beta_2^{(d)} x_{2i} + \dots + \beta_p^{(d)} x_{pi}. \quad (1)$$

²³The reference UDD (average over the reference period 1990-2020) is 1923. The DJU in 2017 is 1864. The hardship index is 0.969.

²⁴This percentage has risen sharply in recent years due to the increase in energy prices. According to the Médiateur de l’Energie, in 2023, “8 out of 10 households said they had turned down their heating in winter to avoid excessive bills; this rate, which was 69% in September 2022, has never been so high” (Press release, Wednesday 18 October 2023).

²⁵We also tested other variables to identify households that restrict their consumption, such as how the household perceives its financial situation or the poverty indicator in living conditions. We obtained results similar to those obtained with the binary variable TEMP.

²⁶As the number of A-rated homes is very low, we have grouped together the A- and B-rated homes.

²⁷We do not include the date of construction among the explanatory variables, because the high proportion of dwellings built before 1949 in the EPC database biases the results: the number of G-rated dwellings is too high (see FIGURE 13c in Appendix A). In addition, the date of construction is not always provided in SRCV, which avoids deleting observations.

Since, for each dwelling i , the sum of all probabilities is equal to 1, then

$$\pi_i^{(d)} = \frac{\exp(\beta_0^{(d)} + \beta_1^{(d)} x_{1i} + \beta_2^{(d)} x_{2i} + \dots + \beta_p^{(d)} x_{pi})}{1 + \sum_{k=1}^5 \exp(\beta_0^{(k)} + \beta_1^{(k)} x_{1i} + \beta_2^{(k)} x_{2i} + \dots + \beta_p^{(k)} x_{pi})} \text{ for } d = C, D, E, F, G, \quad (2)$$

$$\pi_i^{(0)} = 1 - \sum_{d \in \{C, D, E, F, G\}} \pi_i^{(d)} \text{ for A-B rating.} \quad (3)$$

To train and validate the six models, we use Ademe’s EPC database. We set up six samples according to the energy used and the type of dwelling (TABLE 1). Each sample is divided into a training sample with 80% of the data and a test sample with 20%.

Table 1: Samples from the EPC database

Sample	Number of homes
(a) Flats – All electric	311,986
(b) Houses – All electric	145,787
(c) Flats – Electricity & natural gas	141,292
(d) Houses – Electricity & natural gas	123,564
(e) Flats – Electricity and other end-use energy sources	36,875
(f) Houses – Electricity & other end-use energy sources	148,503

Source: Ademe, EPC Existing homes (from July 2021)

We evaluate the performance of each of the models by calculating their precision (TABLE 2) and generating the confusion matrix (TABLE 7 in Appendix B) on the test sample. The models are of good quality, particularly for all-electric dwellings: 88% of EPC labels are correctly predicted for flats and 93% for houses. Performance is slightly less good for homes using energy sources other than electricity and natural gas for heating and domestic hot water, but remains good: 75% of EPCs are correctly predicted for flats and 68% for houses. Above all, if we consider the prediction errors for more than one label using the confusion matrices, they remain rare: they concern less than 0.6% of the EPC labels for dwellings using electricity alone or electricity and natural gas, and respectively 1.5% and 3.9% of the EPC labels for flats and houses using another energy source.

Table 2: Accuracy of the six models on the test sample

Model	Accuracy (exact)	Accuracy (+/- 1 label)
(a) flats – All electric	0.88	0.998
(b) Houses – All electric	0.93	0.999
(c) flats – Electricity & natural gas	0.69	0.994
(d) Houses – Electricity & natural gas	0.85	0.999
(e) flats – Electricity & other end-use energy sources	0.75	0.985
(f) Houses – Electricity & other end-use energy sources	0.68	0.961

Source: Ademe, EPC Existing homes (from July 2021)

In addition, we calculate several measures that allow us to assess the performance of the models for each EPC label, including the *Recall* and the *Precision*. These indicate the ability of the models to correctly detect each class (*Recall*) and show how reliable the predictions are (*Precision*). They are presented in Appendix B.1. The *Recall* is very low for EPC rating A–B, with the exception of all-electric houses: for example, only 8% of all-electric flats rated A–B are correctly detected by the model, 18% and 15% respectively of flats and houses when other energy is used. Models where dwellings use natural gas or other energy sources also have difficulty identifying *leaky flats* (around half of the flats rated G are correctly detected). On the other hand, the *Recall* and *Accuracy* rates

remain high for EPC D and E ratings. Finally, for all-electric homes, the predictions are very reliable: over 90% of homes have a correct prediction of the EPC rating for each energy performance label.

We then use these six models to predict the EPCs of the primary residences in the SRCV database. To find out which model to apply, we set up six samples according to the energy used and the type of dwelling (TABLE 3). The distribution of EPC labels predicted by multinomial logistic

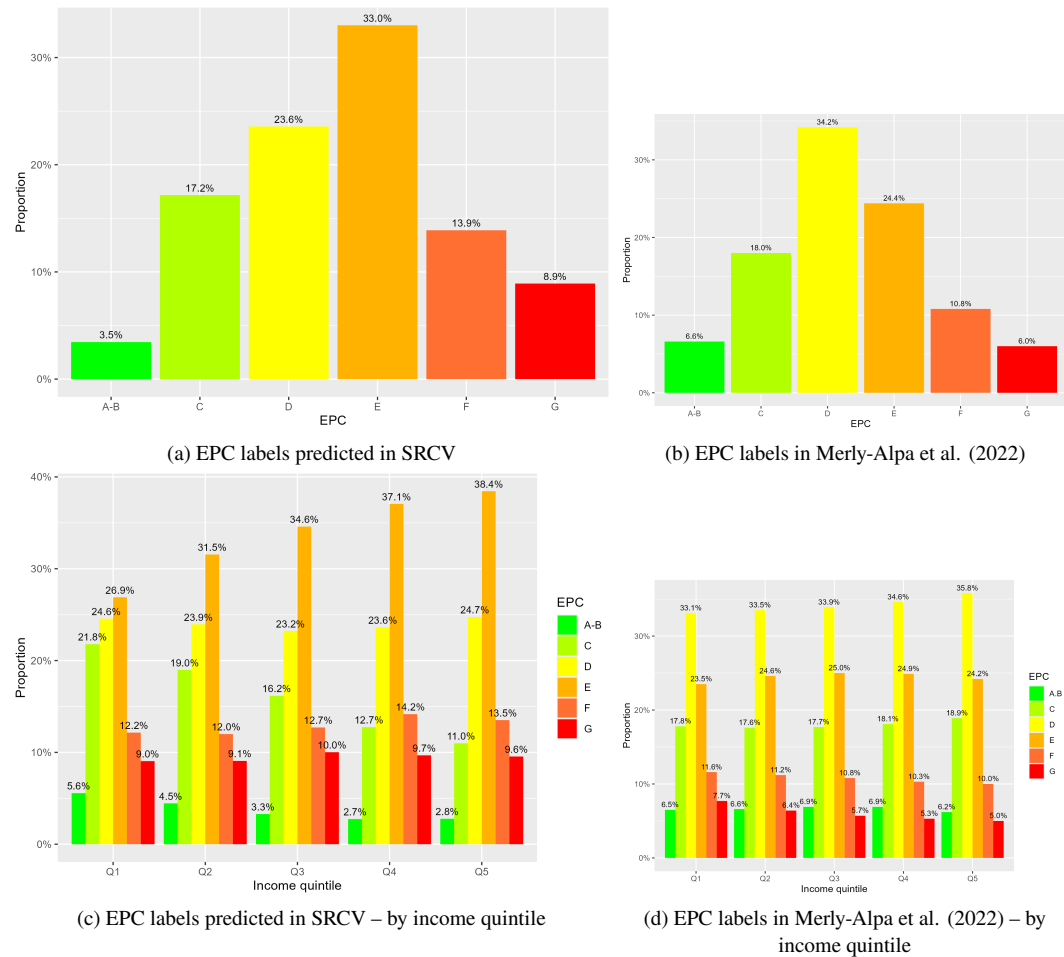
Table 3: Samples in the SRCV database

Sample	number of households
(a) Flats – All electric	1,226
(b) Houses – All electric	1,052
(c) Flats – Electricity & natural gas	1,505
(d) Houses – Electricity & natural gas	4,700
(e) Flats – Electricity & other end-use energy sources	88
(f) Houses – Electricity & other end-use energy sources	819

Source: SRCV2017

regression in SRCV is represented by FIGURE 4. We can compare it to the description of the housing stock by EPC labels produced by Merly-Alpa et al. (2020).

Figure 4: Distribution of EPC labels in SRCV and comparison with Merly-Alpa et al. (2020): prediction by multinomial logistic regression



Source: (a) and (c) SRCV2017; (b) and (d) Merly-Alpa et al. (2020)

Given these differences in the state of the housing stock by energy performance rating, we modify our methodology for assigning EPC ratings to the dwellings of SRCV households in order to obtain a distribution of EPC ratings similar to that of Merly-Alpa et al. (2020), assuming that their estimate is representative of the housing stock in mainland France.

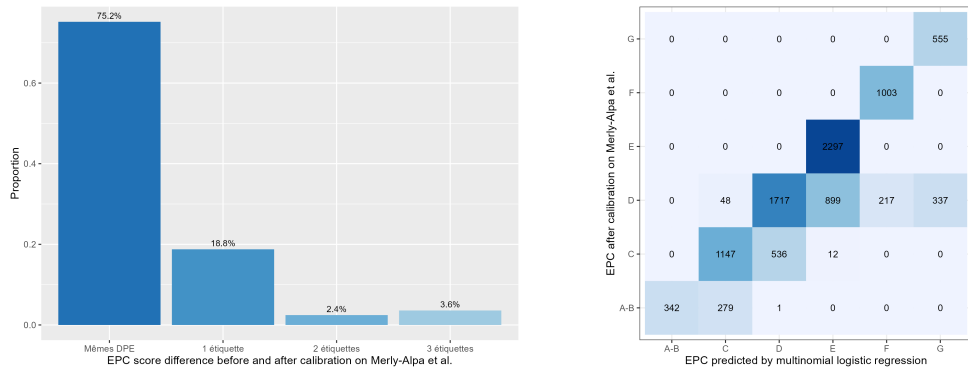
3.3 Adjustment of predictions after multinomial logistic regression

We use the predicted probabilities $\pi_i^{(r)}$ that the dwelling of household i has an EPC rating of r (defined by (2) – (3)). We calculate the number of SRCV households required for each income quintile (q) and EPC label (r), in order to obtain the Merly-Alpa et al. distribution, and proceed iteratively, selecting pairs ($q; r$) in ascending order of the number of households required. Two cases are possible, depending on whether the number of households $n_{q,r}^{\text{model}}$ in quintile q predicted by the model living in a dwelling with an EPC rating of r is lower or higher than that required to obtain the $n_{q,r}^{\text{Merly}}$ distribution of Merly-Alpa et al :

1. $n_{q,r}^{\text{model}} < n_{q,r}^{\text{Merly}}$: we assign an EPC rating of r to households $n_{q,r}^{\text{model}}$ and complete with the other households in the quintile sorted in descending order of $\pi_i^{(r)}$.
2. $n_{q,r}^{\text{model}} > n_{q,r}^{\text{Merly}}$: we sort the households $n_{q,r}^{\text{model}}$ in descending order of $\pi_i^{(r)}$ and assign an EPC rating of r to the first $n_{q,r}^{\text{Merly}}$ of them.

Finally, by comparing the EPC scores predicted by multinomial logistic regression before and after calibration against Merly Alpa et al. (FIGURE 5), we find that the same label is predicted in 75% of cases, and that the corrections are mainly aimed at increasing the number of dwellings with an EPC rating of D (899 E, 217 F and 337 G changed to D). As a result, this method has good accuracy, and prediction errors of more than one label are rare, so it seems to us to be of good quality. FIGURE 15 in Appendix B.2 gives the distribution of the EPC labels according to certain characteristics of the dwelling or household.

Figure 5: Comparison of EPC scores predicted by multinomial logistic regression, before and after correction against Merly Alpa et al.



We are aware that our method of assigning EPC ratings has several limitations. The main one is that it relies on energy bills, which are calculated for standard use in the Ademe’s EPC database on which the model is trained and tested, but which are ‘real’ bills in the SRCV database that we use for predictions. More information on the characteristics of the dwelling and energy consumption, less aggregation in the amounts spent (for energies other than electricity and natural gas, or to distinguish the price of subscriptions), and location data at a finer geographical level in the SRCV survey would

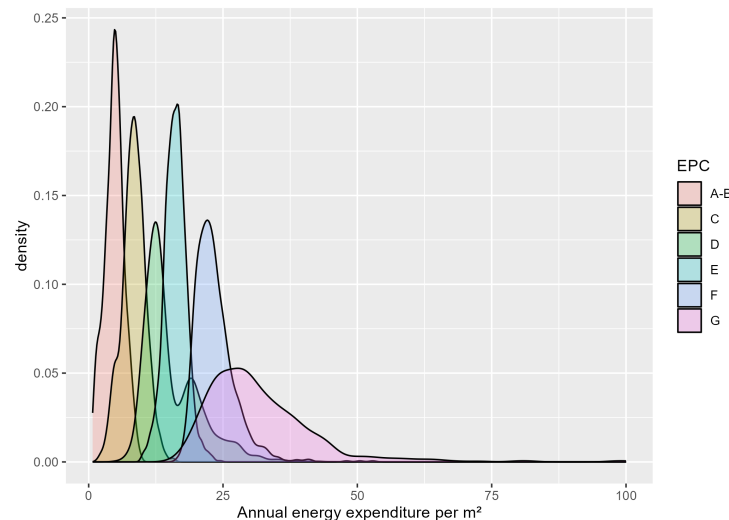
have been necessary to improve the model's performance. Above all, this method is based on the distribution of EPC labels by income quintile provided by Merly-Alpa et al. (2020), which is the only source available on the subject. However, despite having tax and population census sources at their disposal, Merly-Alpa et al. also encountered data limitations and carried out modelling. They also used a database of dwellings for which the EPC rating was awarded before the 2021 recast, which is less reliable. Any bias in the aggregate results of their estimates could have an impact on the EPC ratings we assign to dwellings in the SRCV survey.

4. DETERMINANTS OF ENERGY EXPENDITURE ON HOUSING

4.1 Model

As mentioned above, one of the variables explaining households' energy bills for their homes is the thermal quality of the dwelling, approximated by an EPC rating. This is shown by FIGURE 6: when the EPC deteriorates, annual energy bills per m² increase. This result is not surprising since bills are one of the explanatory variables in the EPC prediction model.

Figure 6: Repartition of annual energy bills per m² according to EPC labels



Source: SRCV2017

Other characteristics of the dwelling can also have an impact on energy bills, such as the type of dwelling (house or flat),²⁸ its surface area,²⁹ its date of construction,³⁰ and even any problems with damp, noise or lack of light. Location (geographical region) can be a determining factor in energy bills, as heating and lighting requirements are lower in sunnier regions.³¹ The urban unit is likely to influence energy spending through differences in access and efficiency of energy infrastructure, or in the case of local policies and regulations.

Finally, certain characteristics of the household impact on its energy bills, such as its financial situation (since more and more consumers are limiting the heating of their homes to avoid excessive

²⁸“the exposed surface of flats and row houses will be smaller than for (semi-) detached residences, requiring less heating for the same level of thermal comfort.” (Brounen et al., 2012). See also Kaza (2010).

²⁹We include area and the logarithm of area to the explanatory variables to capture any non-linear effects in the relationship between energy bills and area.

³⁰See Kaza (2010).

³¹The SRCV database does not contain precise information on the location of household dwellings. However, the ZEAT can be used as an approximation.

energy bills), the fact that it is made up of inactive people who would therefore need to heat their homes throughout the day, the age of the reference person, or their occupancy status (owner or tenant), which can change the incentives to invest in the energy efficiency of their homes. Household appliances and electronic equipment are also likely to have an impact on energy bills: freezer, washing machine, dishwasher, number of computers and televisions.

4.2 Method

To study the impact of the variables listed above on household energy bills, we estimate several linear regression models, with the logarithm of annual energy bills as the dependent variable. More specifically, four models are used, depending on the energy consumed by the household: (1) electricity alone, (2) electricity and natural gas, (3) electricity and other energies for heating and DHW, and (4) electricity, natural gas and other end-use energy sources.

Let's denote X_1, X_2, \dots, X_p all these explanatory variables, Y_i the annual energy bill of household i . The model equation is therefore

$$\log(Y_i) = \beta_0 + \sum_{k=1}^p \beta_k X_{ki} + \epsilon_i, \quad (4)$$

where ϵ_i is the error of the model which summarises the missing information in the linear explanation of the values of Y_i from X_{1i}, \dots, X_{pi} , and the coefficients $\beta_0, \beta_1, \dots, \beta_p$ are the parameters to be estimated.

4.3 Results

The results of the four estimations are presented in TABLE 9 in Appendix C.1. The adjusted R^2 s vary between 0.76 for the estimation of households consuming electricity, natural gas and other end-use energy sources for their dwelling and 0.89 for households whose dwelling is all-electric. The models are of good quality.

Energy bills depend very much on the characteristics of the dwelling, in particular its EPC label and surface area, as well as the household's income. The importance of location varies according to the estimates and the alternatives. For example, on average, households whose entirely electric dwellings are located in the Paris Basin or in the North of France have an annual electricity bill that is 9% lower than that of households in the Île-de-France region.³² On the other hand, there is no difference for other regions or when natural gas or another energy source is also consumed. Similarly, living in Paris rather than in a rural commune reduces electricity bills by 11%, all other things being equal, but has no impact when the household uses several types of energy. However, the 'electricity + natural gas' bill is often slightly lower in urban areas with more inhabitants than in rural commune.

Surprisingly, household characteristics such as the number of people in work or the presence of inactive people are often found to be not statistically significant. Only a few differences can be observed depending on the energy consumed: an 'all electric' bill will be on average 9% higher for a single-parent family and 6% higher for a couple without children than for a single person; an 'electricity + other' bill 8% and 6% higher for a couple with and without children respectively than for a single person. The number of children is statistically significant only for the 'electricity + gas' bill, which increased by an average of 2% per additional child. No influence is found for poverty in living conditions. Finally, the dishwasher is the only item of equipment to have an impact on energy costs (except for electricity and gas consumers), with an increase of between 4% and 8%. As pointed out

³²This percentage is obtained by using the following formula to interpret the coefficient in a log-linear regression model: $(\exp(-0.0954) - 1) * 100 = 9$.

previously by [Liao and Chang \(2002\)](#) (for the United States), the energy bills for households using natural gas rise with the age of the reference person.

Interaction terms between several variables have been added to the model: between the EPC rating and the income quintile, and between the EPC rating and the type of dwelling.³³ These terms improve the accuracy of the model. Above all, they make it possible to examine how the effect of the EPC label on energy expenditure varies according to household income or type of dwelling (flat or house), and to capture the non-linear relationships between the explanatory variables. It is conceivable, for example, that a household with a higher income in a dwelling of poor thermal quality would use more energy-efficient appliances, which could mitigate the effect of a poor EPC rating on its energy bill. These coefficients can be used to calculate matrices of transition expenditure from one EPC rating to another (see Appendix C.2). Knowledge of these transition matrices is essential for studying the effects of home energy renovations (i.e. those that result in at least one jump in the EPC label).

4.4 Importance of the EPC rating on energy bills

For example, for a household living in an all-electric house (TABLE 10 in Appendix C.2) belonging to the 1st income quintile (Q1), its annual electricity bill falls by 58% if it moves from an EPC rating C to an EPC rating A–B, by 34% from rating D to rating C, by 29% from rating E to rating D, by 28% from rating F to rating E, and finally by 35% from rating G to rating F. If the same household belongs to a higher income quintile, the reduction in its bill is even greater if it moves from an EPC rating C to an EPC rating A–B. On the other hand, the savings on bills resulting from a better EPC rating are lower for flats than for houses. This difference is explained by the fact that detached homes, which have more external walls and a larger surface area, see their energy consumption drop significantly thanks to improved insulation and heating; whereas flats, which have fewer exposed surfaces and already benefit from the heat of neighbours, have less pronounced gains. Although there are some variations between quintiles (particularly Q3 and Q4), after EPC improvement work and obtaining an EPC rating E, the energy consumption of a *leaky home* can be reduced by around a quarter (if it was initially F) or half (if it was G).

The annual energy bill of a household consuming electricity and natural gas (TABLE 11 in Appendix C.2) is reduced by an average of 40% if the EPC rating of its dwelling goes from C to A–B, by 34% from D to C and by 25% from F to E. However, the impact of moving from an E label to a D label varies according to income quintile: –25% for the 1st and 2nd income quintiles, compared with only –6% for the Q3, Q4 and Q5. Similarly, there are differences when moving from an EPC rating G to rating F, ranging from a 42% reduction in expenditure for Q4 to 19% for Q2. Finally, the only change between living in a house or a flat concerns EPC ratings A–B and C, with slightly greater reductions in bills for flats.

In Appendix C.2 TABLES 12 and 13 are the transition matrices for households using energy sources other than electricity and natural gas. An improvement in the EPC rating from C to A–B reduces annual expenditure on electricity and other energy sources by 60% (68% for Q5) if the household lives in a house and by 30% if it lives in a flat (44% for Q5). As before, this difference can be explained by the larger surface area and greater number of exposed walls in houses, which enable them to benefit more from energy improvements, but also by the fact that heating systems in flats, especially if they are collective, are often less modifiable and the use of other energy sources (fuel oil, wood) is lower. However, if natural gas is also consumed, the impact is the same for a house and a flat: –42%. For the other EPC labels, moving from an EPC rating D to rating C reduces the total bill for electricity, natural gas and other energy sources by 40% (and even 45% if the household does not

³³We also test several interactions between the EPC rating and other explanatory variables, but they do not increase the R², these two variables being the most significant

use natural gas; 30% if it is in Q5); the reduction will be 24% for a move from an EPC rating F to rating E and 40% from G to F (if the household does not use natural gas, the impact of moving from G to F varies according to income quintiles, ranging from -12% to -46%). Finally, we again obtain surprising results for the transition from an EPC rating E to rating D: the reduction in bills is very small from the third income quintile onwards. This may be due to the methodology used to predict the EPC rating of dwellings: in order to obtain the same distribution of labels by income quintile as Merly-Alpa et al., 899 EPC ratings predicted as E by the model (which contains the energy bill as an explanatory variable) were corrected to D (FIGURE 5). Another explanation could be the existence of more significant rebound effects from the third income quintile onwards.³⁴

These results show the significant impact that improving an ECD rating, even by just one label, can have on energy bills. They demonstrate the need to invest in the thermal renovation of residential buildings in order to reduce energy costs and therefore fuel poverty, by helping households to improve the energy efficiency of their homes. For the most modest households living in poorly insulated homes, the situation can be financially difficult and the risk of fuel poverty high. In order to implement public policies to support these households and promote a fair transition, it is necessary to quantify the basket of goods needed to live decently. This includes the energy required by households to meet their basic needs in their homes, which is the subject of the rest of this document.

5. HOW MUCH ENERGY DO YOU NEED TO LIVE DECENTLY IN YOUR HOME?

5.1 Methodology

The first step in estimating minimum energy levels is to find a way of quantifying the notion of ‘decent living’. Following the approach of [Chaton and Guillerminet \(2023\)](#), we consider only *strained* households.³⁵ There are 4,232 of them.

Minimum energy levels can be determined either by value, based on bills (as above, but for the *strained* household sample), or by volume. In the first case, the budgets required by households (depending on their characteristics and those of their home) to buy the energy they need to live decently (in 2017) are determined and presented in 5.2. In the second case, we determine them on the basis of the annual expenditure provided in SRCV and assumptions about the price of the energy used. We assume that households have subscribed to the regulated tariffs for natural gas and electricity. We use the prices inclusive of all taxes, available at data.gouv.fr.³⁶ This is a two part tariff: a lump-sum fee and a per unit charge.

For electricity, there are two options: (1) the base option which applies a single tariff with a fixed price per kWh throughout the day (2) the peak/off-peak option (HP/HC option) with a price per kWh that varies according to the time of day, higher in peak than in off-peak periods. So, the price depends on the option chosen and the power subscribed (according to the surface of the dwelling, the type of heating used and the presence of any specific electrical appliances).³⁷ TABLE 14 in Appendix D.1 provides information on the assumptions made concerning the option chosen and the power

³⁴Improved productive or energy efficiency can actually lead to greater use of the product and its associated energy: “It is wholly a confusion of ideas to suppose that the economical use of fuel is equivalent to a diminished consumption. The very contrary is the truth.” (Jevons, 1866). “Efficiency and behaviour may influence each other, because a higher efficiency leads to cheaper service prices and hence may change consumer behaviour with respect to choosing. This so-called rebound effect is important for end uses such as space heating, water heating and lighting.” (Haas, 1997).

³⁵We define these households on the basis of two variables: perception of financial situation (question code in SRCV: NIVACTB) and poverty in living conditions (question code: PCDVFR). We assume respond that they are struggling but are getting by, or that things are okay but they should be careful. In addition, they are not poor in terms of living conditions, in order to avoid also taking into account people who restrict themselves.

³⁶See [Historique des tarifs réglementés de vente d’électricité pour les consommateurs résidentiels](#) and [Historique des tarifs réglementés de vente de gaz naturel pour les consommateurs résidentiels](#).

³⁷In the case of the HP/HC option, it also depends on the quantity consumed each period.

contracted, as well as the corresponding electricity tariffs in 2017. For natural gas, the price per kWh and the subscription depend on the consumption class: Base, B0, B1 and B2i, determined by the use of natural gas. The description of these four tariffs, the way in which we attribute them to households in the SRCV database and the corresponding prices are presented in Appendix D.2 (TABLE 15). From these assumed electricity and natural gas tariffs, and given the energy expenditure declared by households, we can finally deduce the quantities of electricity and natural gas consumed.

The minimum level of energy needed to live decently is specific to each household: it may depend on the characteristics of its dwelling, in particular its surface area and its EPC rating (proxy for thermal quality), its location (in a region with more or less sunshine, for example), and the type of household (number of inhabitants, children, working or non-working). To quantify this, we use a linear regression model with the logarithm of the annual quantity of energy consumed (or the logarithm of the annual energy bill) of *strained* households as the dependent variable. Among the *strained* households, we consider two types: those whose dwellings are entirely electric and those who consume both electricity and natural gas. We are obliged to focus solely on these households and eliminate those that use another energy source for heating or DHW, as the SRCV survey does not specify the other types of energy consumed.

The explanatory variables considered are the same as those used to estimate household energy bills (Section 4), with the exception of poverty in living conditions, which is already taken into account in the ‘*strained* household’ sample. Let X_1, X_2, \dots, X_p be all these explanatory variables, Z_i the annual quantity of energy consumed by the *strained* household i , then the model equation is

$$\log(Z_i) = \beta_0 + \sum_{k=1}^p \beta_k X_{ki} + \epsilon_i, \quad (5)$$

where ϵ_i is the error term and $\beta_0 \dots \beta_k$ the parameters to be estimated.

The parameters were estimated for both samples: *strained* households consuming only electricity and those also consuming natural gas. While the first estimate for households consuming only electricity does not raise any particular difficulties, the second raises the question of the distinction between the quantity of electricity and the quantity of natural gas. The two types of consumption are in fact interdependent: the more electricity you consume, the less natural gas you consume, and vice versa. We model the sum of the quantities of electricity and natural gas consumed, and include the share of electricity in total energy consumption among the explanatory variables. This method has the advantage of being simple to implement and interpret. To take account of a possible non-linear effect of the weight of electricity consumption on total energy consumption, we consider this weight squared as an explanatory variable.³⁸

5.2 Minimum energy budget

We estimate the minimum energy expenditure needed to live decently (in 2017). The results of the two regressions (all electric and electricity and natural gas) on the sample of *strained* households’, with the logarithm of the annual energy bill as the dependent variable, are presented in TABLE 4. They are of good quality, with adjusted R^2 s of 0.907 for *strained* households using only electricity for their dwellings and 0.866 for those using both electricity and natural gas.

³⁸Another solution to account for the interdependence of electricity and natural gas consumption would have been to use a SUR (Seemingly Unrelated Regression) model, which consists of a system of several regression equations, each with its own dependent variable and potentially different exogenous explanatory variables, but whose error terms are correlated. However, with this estimate, we obtain a lower R^2 than with the one we have retained; moreover, we cannot use exactly the same explanatory variables in the two equations.

Table 4: Estimate of the logarithm of the annual energy bill, for *strained* households

	All electric	Electricity & natural gas
(Intercept)	3.946 ***	4.7913 ***
EPC (ref : D)		
EPC A-B	-0.985 ***	-0.9862 ***
EPC C	-0.6456 ***	-0.4737 ***
EPC E	0.2804 ***	0.1751 ***
EPC F	0.6019 ***	0.5342 ***
EPC G	0.8632 ***	0.7237 ***
Type of accommodation (ref.: flat)		
House	0.1025 ***	0.1363 ***
EPC x Type de logement		
EPC A-B x House	-0.5586 ***	0.0588
EPC C x House	0.1704 ***	0.0328
EPC E x House	-0.0216	-0.0701 **
EPC F x House	-0.0552	-0.1436 ***
EPC G x House	0.0789	0.0067
Surface	0.0021 ***	0.0007 *
log(Surface)	0.5935 ***	0.4781 ***
Number of rooms	-0.0223 ***	0.0042
ZEAT (ref : Ile-de-France)		
Bassin parisien	-0.0909	0.0067
Centre-Est	-0.0643	0.0214
Est	0.0053	0.0524
Méditerranée	0.0177	0.0052
Nord	-0.0379	-0.0053
Ouest	-0.0429	0.0455
Sud-Ouest	-0.0279	0.0227
Urban unit (ref: rural commune)		
2 000 to 4 999 hab	0.0572	-0.0071
5 000 to 9 999 hab	-0.0495	-0.0592 **
10 000 to 19 999 hab	0.0174	-0.0383
20 000 to 49 999 hab	-0.0671 *	-0.0315
50 000 to 99 999 hab	-0.0755 *	0.021
100 000 to 199 999 hab	-0.049	-0.0337
200 000 to 1 999 999 hab	-0.0164	-0.0154
Paris	-0.0811	-0.0249
Date of construction (ref: after 1990)		
Before 1949	0.0122	0.0342 **
From 1949 to 1974	-0.0315	0.0164
From 1975 to 1981	0.0054	0.017
From 1982 to 1989	-0.0163	0.0155
Housing occupancy status (ref: owner)		
Tenant or sub-tenant	0.0217	-0.0225 *
Type of household (ref: single person)		
Single parent family	0.0365	-0.0036
Couple without child	0.0869 ***	0.0273 *
Couple with at least one child	0.0038	-0.0224
Other household (complex household)	0.023	-0.0156
Number of working people	-0.0097	0.0095
Number of children	0.0153	0.0229 **
Inactive in the household (ref: no)		
Yes	0.0097	0.0097
Reference person's age	-0.0002	0.0009 *
		.../...

	All electric	Electricity & natural gas
... / ...		
Pierced roof, moisture (ref: no)		
Yes	0.0104	0.0025
Noise (ref: no)		
Yes	-0.0215	-0.0095
Difficult/expensive to heat (ref: no)		
Yes	0.0469 **	0.0495 ***
Dark (ref: no)		
Yes	0.0014	-0.0176
Freezer (ref: no)		
Yes	0.0371	0.0049
Washing machine (ref: no)		
Yes	0.0151	0.0406
Dishwasher (ref: no)		
Yes	0.0438 **	0.0295 **
Number of computers	0.0088	0.0016
Number of televisions	0.0062	0.0166 ***
Income quintile (ref: Q1)		
Q2	0.0875 ***	0.0489 ***
Q3	0.1219 ***	0.1358 ***
Q4	0.1818 ***	0.1911 ***
Q5	0.213 ***	0.1998 ***
Gas bottle (ref: no)		
Yes	-	-0.0894 ***
Electricity weight	-	-0.009 ***
(Electricity weight) ²	-	0.0001 ***
Number of observations	819	1 764
Adjusted R²	0.907	0.866

Note: P-value : *** p<0.01, ** p<0.05, * p<0.1.

We note that in both estimates the dependent variable is almost totally explained by the EPC rating: most of the other explanatory variables are not statistically significant at the 10% level. As in the estimation using the whole sample (i.e. not limited to *strained* households), the income quantiles are found significant. Since we are looking at *strained* households, we might have thought that these bills, and consequently their energy expenditure needed to live comfortably in the dwelling, would not depend on household income. But consumption habits can vary according to income. For example, those with a little more money may attach more importance to thermal comfort or use more appliances. The lack of significance of household composition is more surprising: it was expected that the minimum amount of energy needed to live decently would be greater for a couple with children, a single-parent family or economically inactive people, as is the case in the reference budgets quantified by the ONPES report (Gilles et al., 2014). One possible explanation is that the expected effects of household composition are already taken into account by other explanatory variables in the model, such as surface area or type of dwelling, since families with children often tend to live in larger dwellings or houses. Perhaps larger households also adopt compensatory behaviors that limit their energy consumption, by being stricter about the use of electronic appliances or heating; or quite simply that lifestyles and energy habits are relatively homogeneous within *strained* households, which are obliged to be careful with their spending, whatever their composition. Finally, whether we are talking about electricity alone or a combination of electricity and natural gas, consumption varies according to the type and size of dwelling.

To facilitate interpretation of the regression coefficients, we define two reference situations, depending on the type of dwelling.³⁹ It is important to stress that the choice of these reference situations (defined in the box) is arbitrary and made in the interests of saving space.

³⁹These reference situations are defined by taking the most frequent modality for each type of dwelling for qualitative variables, or the median for quantitative variables.

REFERENCE SITUATIONS

- **Type 1:** A household living in a 100 m² house, with four rooms, an EPC rating D and built after 1990. This is a working couple with two children that own their home and belong to the 4th income quintile. They live in a rural commune in the Paris Basin. The home is equipped with a dishwasher, a freezer, a washing machine, a computer and a television. It is not too dark, too damp, too noisy, too difficult or too expensive to heat.
- **Type 2:** A household living in a three-room 60 m² flat with an EPC rating C, built after 1990. This is a single working person without children, renting their home and belonging to the 1st income quintile. She or he lives in Paris. The property does not contain a dishwasher, but does have a freezer, washing machine, computer and television. It is not too dark, too damp, too noisy, or too difficult or expensive to heat.

5.2.1 All-electric housing

The minimum energy expenditure for the two reference situations is presented in Figure 7.

A **Type 1** household needs an annual electricity budget of 1,217 euros. If the surface area of the house is 60 m², this amount decreases to 827 euros, but increases to 1,513 euros for 130 m². Furthermore, if the house has one more room (five instead of four), 27 euros less will be needed to live decently. There are also significant variations depending on the EPC rating: the minimum energy bill can be as low as 213 euros for an EPC rating A–B and as high as 3,121 euros for an EPC rating G. Finally, we estimate that the reference budget lies within a range of between €1,014 and €1,255, depending on the income quintile to which the household belongs.

The minimum annual expenditure on electricity for a **Type 2** household is €322. This rises to €1,120 and €1,454 for an EPC rating F and rating G respectively. If the surface area is 30 m², the necessary budget is reduced to €200; on the other hand, it is €473 for a 100 m² flat.

5.2.2 Dwellings where households use electricity and natural gas

For households consuming both electricity and natural gas, the minimum energy expenditure for the two reference situations is presented in Figure 8.

They are estimated at €1,529 for a **Type 1** household and €464 for a **Type 2** household. The energy budget needed to maintain a decent standard of living is strongly influenced by the surface area and EPC rating of the dwelling: it is reduced to €1,166 for a 60 m² house and rises to €1,768 if the surface area is 130 m² (with a reference EPC rating D); it also varies between €605 for an EPC rating A–B and €3,173 for an EPC rating G (with a reference surface area of 100 m²). Similarly, for a person living in a 60 m² flat with an EPC rating C, the minimum energy bill varies from €278 to €1,535 if the energy performance label is changed, and from €326 to €608 if the surface area is increased to 30 m² and 100 m² respectively.

5.2.3 Comparison with reference budgets quantified by ONPES

According to Baudry et al. (2017), in 2017 a household's current expenditure on housing-related energy was €1,520. This average value is obviously higher than the average value of the minimum energy levels. It is therefore preferable to compare our results with the reference budgets

Figure 7: Estimated annual energy bill for a *strained* household (and variations compared with two reference situations) - All electric

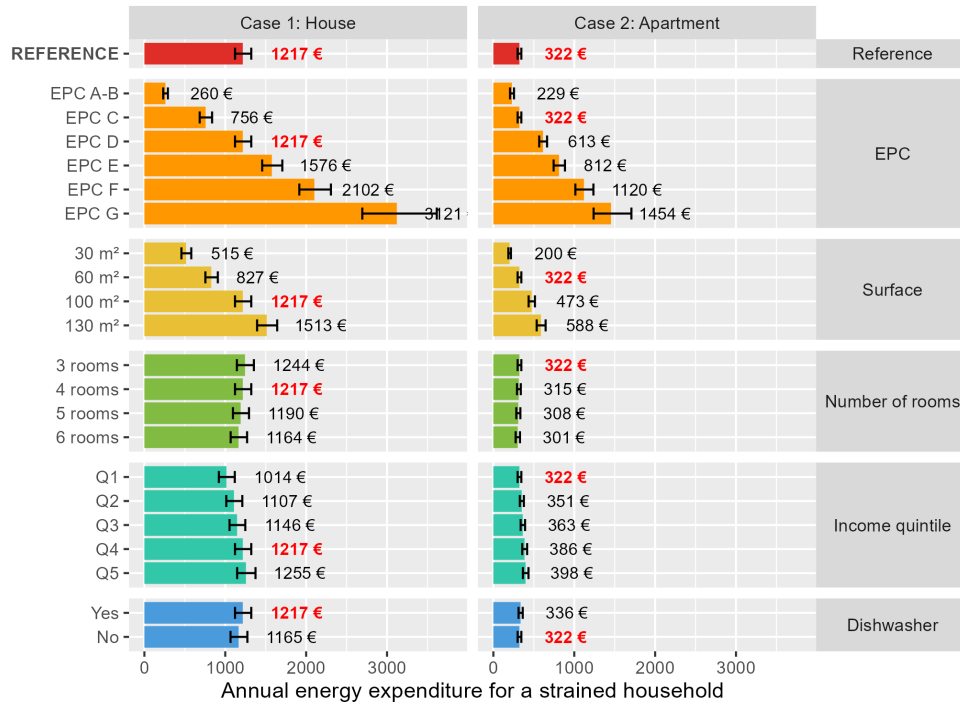
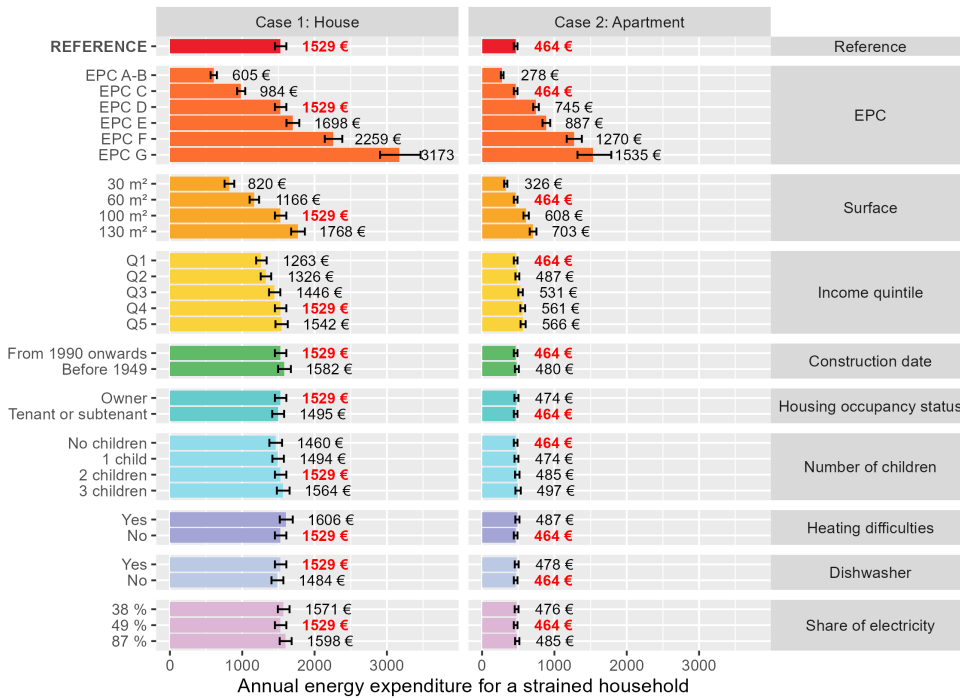


Figure 8: Estimated annual energy bill for a *strained* household (and variations compared with two reference situations) - Electricity and natural gas



calculated by (ONPES, 2014-2015).⁴⁰ ONPES quantified a reference energy budget for housing of between €78 (single person) and €135 (couple with two children) per month, depending on the family configuration, or between €936 and €1,620 per year. These estimates are therefore much higher than our results for the two reference situations where households occupy all-electric homes; on the other hand, they are closer to those we obtain when electricity and natural gas are used jointly, particularly for a couple with two children. This comparison is purely informative since, as mentioned in the introduction, the ONPES study was carried out for two medium-sized towns (Tours and Dijon) and does not vary according to the surface area and EPC rating of the dwelling, which have a significant impact. We can see, for example, that the reference budget estimated by the consensus group for a single person is similar to what we find when we assume that their flat has an EPC rating E; the same applies to the budget quantified for a couple with two children, which is close to our results when their home has an EPC rating E.

5.3 Minimum energy level for housing

The results of the volume estimates of the minimum energy levels for a decent life in a dwelling (all-electric or using electricity and natural gas), given our assumptions on natural gas and electricity prices (see D.1 and D.2), are presented in TABLE 5.

Table 5: Estimate of the logarithm of the annual quantity of energy consumed, for *strained* households

	All electric	Electricity & natural gas
(Intercept)	4.9796 ***	6.8991 ***
EPC (ref : D)		
EPC A-B	-1.2716 ***	-1.462 ***
EPC C	-0.8471 ***	-0.6234 ***
EPC E	0.3284 ***	0.2157 ***
EPC F	0.7069 ***	0.6671 ***
EPC G	1.0213 ***	0.9114 ***
Type of accommodation (ref.: flat)		
House	0.1064 *	0.1653 ***
EPC x Type de logement		
EPC A-B x House	-1.1154 ***	0.2527 ***
EPC C x House	0.2969 ***	0.0803 **
EPC E x House	-0.0374	-0.0805 **
EPC F x House	-0.0856	-0.1908 ***
EPC G x House	0.0473	-0.0634
Surface	0.0016	0.0008
log(Surface)	0.7495 ***	0.5513 ***
Number of rooms	-0.0321 **	0.006
ZEAT (ref: Ile-de-France)		
Bassin parisien	-0.1403	-0.0051
Centre-Est	-0.0825	0.0323
Est	0.0124	0.0606
Méditerranée	0.0489	0.0213
Nord	-0.0941	-0.0082
Ouest	-0.0575	0.0632
Sud-Ouest	-0.0215	0.0264
		... / ...

⁴⁰Price rises in France were low between 2015 and 2017: according to INSEE, annual inflation was 0.0% in 2015, 0.2% in 2016 and 1.0% in 2017.

	All electric	Electricity & natural gas
.../...		
Urban unit (ref: rural commune)		
2 000 to 4 999 hab	0.0775	-0.0175
5 000 to 9 999 hab	-0.0537	-0.0749 **
10 000 to 19 999 hab	0.0519	-0.038
20 000 to 49 999 hab	-0.094	-0.035
50 000 to 99 999 hab	-0.0977	0.0169
100 000 to 199 999 hab	-0.0745	-0.0458
200 000 to 1 999 999 hab	-0.007	-0.0366
Paris	-0.0989	-0.0563
Date of construction (ref: after 1990)		
Before 1949	0.0244	0.0457 **
From 1949 to 1974	-0.0811	0.0186
From 1975 to 1981	0.0028	0.0292
From 1982 to 1989	-0.0263	0.0167
Housing occupancy status (ref: owner)		
Tenant or sub-tenant	0.049	-0.0352 *
Type of household (ref: single person)		
Single parent family	0.0236	0.0113
Couple without child	0.0923 **	0.0491 **
Couple with at least one child	-0.0514	-0.0082
Other household (complex household)	-0.067	0.0103
Number of working people	0.0111	0.0135
Number of children	0.0179	0.0238 *
Inactive in the household (ref: no)		
Yes	0.0253	0.0131
Reference person's age	-0.0007	0.001
Pierced roof, moisture (ref: no)		
Yes	0.0242	0.0026
Noise (ref: no)		
Yes	-0.0431	-0.0100
Difficult/expensive to heat (ref: no)		
Yes	0.0398	0.0624 ***
Dark (ref: no)		
Yes	-0.0085	-0.0198
Freezer (ref: no)		
Yes	0.0795	-0.0046
Washing machine (ref: no)		
Yes	0.0885	0.0494
Dishwasher (ref: no)		
Yes	0.076 **	0.0337 **
Number of computers	0.0117	0.0022
Number of televisions	0.0058	0.0197 **
Income quintile (ref: Q1)		
Q2	0.1224 ***	0.0412 **
Q3	0.173 ***	0.1575 ***
Q4	0.249 ***	0.2257 ***
Q5	0.2743 ***	0.2403 ***
Gas bottle (ref: no)		
Yes	-	-0.0105
Electricity weight	-	-0.0234 ***
(Electricity weight) ²	-	0.0001 ***
Number of observations	819	1 764
Adjusted R²	0.840	0.882

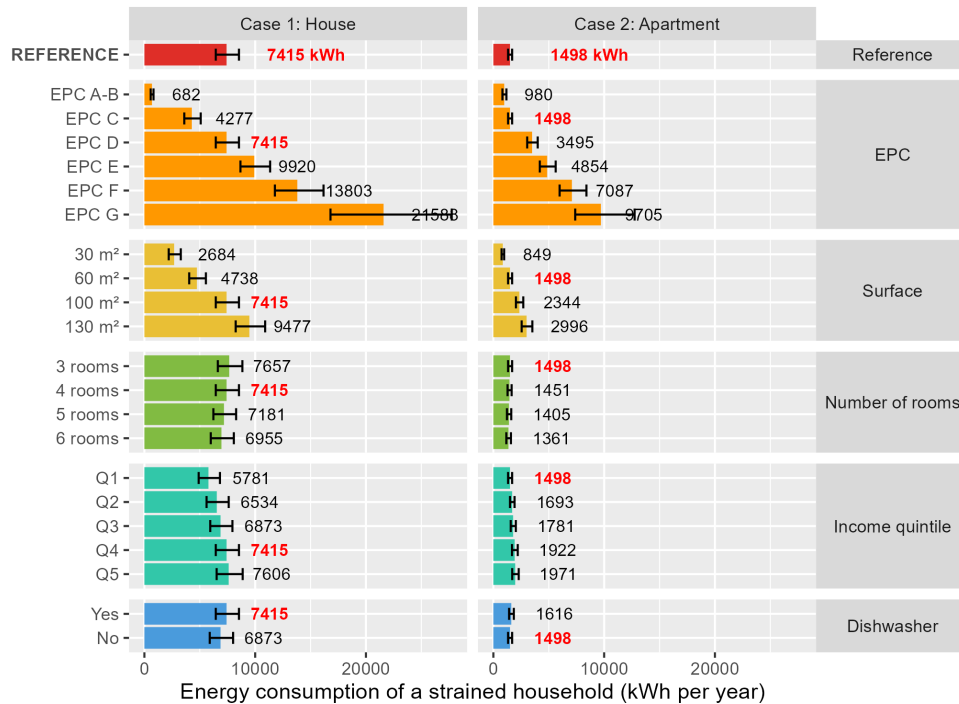
Note: P-value : *** p<0.01, ** p<0.05, * p<0.1.

As with the estimation of energy bills, the models are of good quality, with a slightly lower R² for households with all-electric dwellings (0.84). The significance of the variables is also very similar. As with energy bills for housing, to make it easier to interpret the regression coefficients, we are looking more specifically at the two reference situations defined above (see box).

5.3.1 All-electric housing

FIGURE 9 shows the energy consumption of *strained* households whose dwelling is all-electric. For a **Type 1** household, the annual amount of energy needed to live decently is 7,415 kWh. This minimum amount of energy depends very much on the house’s EPC rating. It ranges from 682 kWh (if the EPC rating is A–B) to 21,588 kWh (if the EPC rating is G). If the surface area of the house is larger, for example 130 m², this annual benchmark rises to 9,477 kWh (+2, 062 kWh), while it falls to 4,738 kWh (–2, 677 kWh) if the surface area is reduced to 60 m². Electricity consumption decreases with the number of rooms (7,657 kWh per year if there are three rooms, 6,955 for six), which may seem counter-intuitive at first glance, but can be explained by the fact that in homes with many rooms, some of them are probably little used or heated, which reduces the minimum energy requirements (the surface area effect having already been captured). Finally, there are some differences depending on the income quintile to which the household belongs: annual electricity consumption is 5,781 kWh if the household is in Q1 and 7,606 kWh if it is in Q5.

Figure 9: Estimate of the annual quantity of energy consumed by a *strained* household (and variations in relation to two reference situations) - All electric

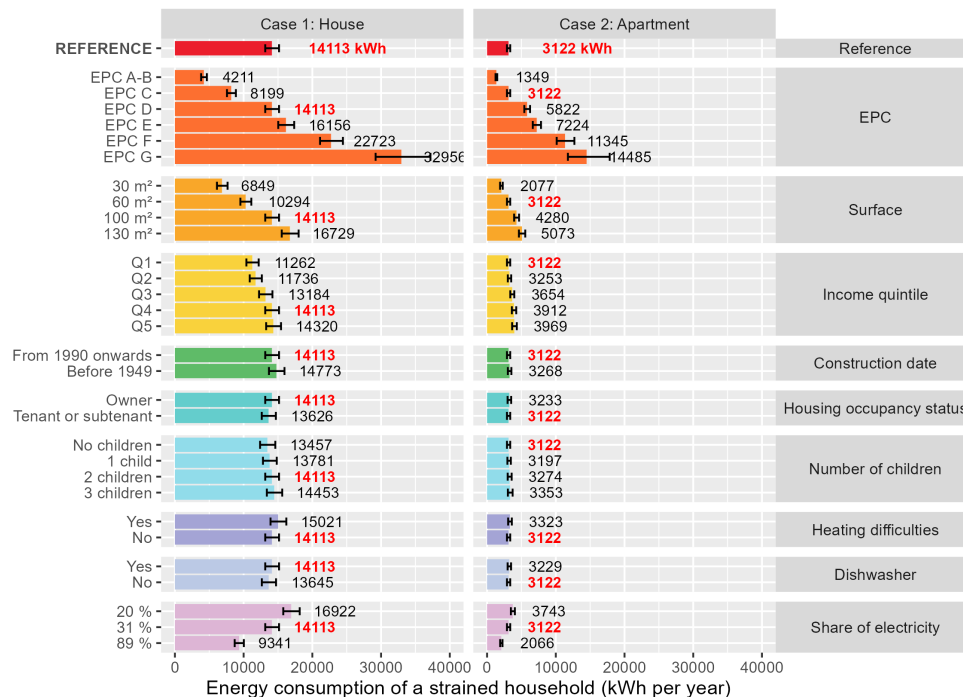


For a **Type 2** household, the minimum level of energy needed to live decently is 1,498 kWh per year. This drops to 980 kWh for an EPC rating A–B, but rises to 7,087 kWh (+6, 126 kWh for an EPC rating F compared with an EPC rating C) or 9,705 kWh (+8, 997 kWh for an EPC rating G) if the property is a heat sink. Depending on the size of the flat, this person’s minimum annual electricity needs will also vary: for example, 849 kWh if the flat is 30 m², 2,344 kWh for 100 m². The differences according to income are fairly small, which could mean that consumption habits are relatively homogeneous for this type of household. Finally, the presence of a dishwasher in the flat increases the amount of essential energy by 130 kWh per year.

5.3.2 Dwellings where households use electricity and natural gas

The minimum energy levels for these two reference situations where households use both electricity and natural gas are shown in (FIGURE 10). The basic energy needs of a **Type 1** household are 14,113 kWh per year. Depending on the EPC label, the differences can be very large: 9,902 kWh less per year for an EPC rating A–B, 8,610 kWh more for an EPC rating F, and up to 18,843 kWh more for an EPC rating G. For a house measuring 60 m² instead of 100 m², the minimum annual amount of energy needed to live decently is reduced to 10,294 kWh (–3, 819 kWh), while it rises to 16,729 kWh (+2, 616 kWh) if the house is 130 m². There is a slight difference depending on the date of construction, which is after 1990 in the reference situation: a home built before 1949 requires 660 kWh more annual energy consumption. Other characteristics modify the minimum energy requirements: for example, occupancy status (–488 kWh per year if the household rents rather than owns), the number of children (13,781 kWh per year for a couple with one child, 14,453 kWh if they have three) or, as before, whether or not the household has a dishwasher (–468 kWh per year if they don't). Finally, the weight of electricity in total consumption has an impact on essential energy needs: they are 16,922 kWh per year if electricity accounts for 20% of consumption, but only 9,341 if it accounts for 89% (the reference weight being 31%).

Figure 10: Estimate of the annual quantity of energy consumed by a *strained* household (and variations in relation to two reference situations) - Electricity and natural gas



A **Type 2** household needs 3,122 kWh of energy per year to live decently. This rises to 1,349 kWh if the flat has an EPC rating A–B, and to 11,345 kWh (14,485 kWh) if it has an EPC rating F (G). Minimum energy levels also vary according to surface area: for example, they are 2,077 kWh per year for 30 m², and 4,280 for 100 m². As before, there are slight differences according to income quintile, date of construction, occupancy status, number of children, difficulty of heating or presence of a dishwasher. The impact of the weight of electricity in electricity and natural gas consumption remains: the minimum level of energy needed to live decently rises to 3,743 kWh per year if electricity accounts for only 20% of the total, but falls to 2,066 kWh per year if it accounts for 89%.

6. CONCLUSIONS

By determining the amount of energy needed to live decently in an all-electric home or a home with electricity and gas, we contribute to the knowledge of the basket of essential goods specific to each household. This basket is used to determine the income needed to live decently, taking into account different price scenarios. This information is important for reducing fuel poverty and promoting a fair energy transition, while ensuring that the measures taken do not exacerbate inequalities.

For example, we estimate that a working couple with two children, in the 5th income quintile, owner of their home (all-electric, 100 m², four rooms, EPC rating D, built after 1990, equipped with a dishwasher, freezer, washing machine, computer and television) in a rural commune in the Paris Basin need to consume 7,606 kWh per year to live decently. This household will have to pay the sum of €1,861.⁴¹ This cost is much higher than the maximum amount of the energy voucher, which is 277 euros per year (in 2024).

The main problem in determining the levels of housing energy needed to live decently is the lack of a recent database representative of French households and their housing. To remedy this shortcoming, we merged two databases (SRCV survey and ADEME's EPC database). A multinomial logistic regression model was used to assign an EPC rating to each dwelling in the SRCV survey, with some adjustments based on information on the housing stock provided by [Merly-Alpa \(2023\)](#). This has enabled us, among other things, to estimate the impact of household characteristics, housing and location on energy costs. Based on the results of these estimates, it is possible to calculate the savings on bills generated by switching to a better EPC rating. To illustrate this, we have determined the transition matrices of bills from one EPC label to another for houses, flats, using electricity only, electricity and natural gas or electricity, natural gas and other energy sources. Knowledge of this matrix is important when it comes to making decisions about renovating homes for energy efficiency (see for example [Chaton \(2023\)](#)). We have determined it in terms of value, but with assumptions about energy prices, we could have determined it in terms of quantity, i.e. what is the gain in kWh from improving the EPC rating.

Estimating minimum energy levels reveals significant differences depending on the EPC rating. The type of dwelling and its surface area also have an impact. Household composition, on the other hand, does not appear to be statistically significant. For example, a couple with two children living in a 100 m² house with an EPC rating D needs 7,415 kWh of energy per year if they use electricity alone, and 14,113 kWh per year if they use both electricity and natural gas. These quantities fall to 1,498 and 3,122 kWh per year respectively for a single worker renting a 60 m² flat with an EPC rating C in Paris. To consume these decent levels of energy, this family of four needed, in 2017, 1,217 or 1,529 euros per year, depending on whether or not they used gas, and this single person 322 or 464 euros per year. Our estimates of the minimum levels of energy consumption and expenditure necessary to live decently in one's home differ from the information provided by certain energy companies.⁴² On the one hand, the figures provided by energy suppliers are not specific to the EPC rating of the dwelling and, on the other hand, for a given EPC rating, the consumption of non-poor households is higher than or equal to the minimum levels.

To complete our analysis, it would be interesting to determine the minimum quantity of other essential goods as well as the cost of the essential basket, specific to each household. We have tried to isolate from this basket other items (excluding energy) for housing, in particular water and rent, and to define decent levels for these items. But the quality of these variables in SRCV does

⁴¹Based on the November 2024 peak/of-peak option tariff (0.27 €/kWh / 0.2068 €/kWh)

⁴²e.g. according to [EDF solution solaire](#), the average consumption of a family of four living in an all-electric house (heating, hot water and cooking) measuring 100 m² is 14,100 kWh.

not allow us to obtain satisfactory results. The study we carried out on France can also be carried out on European countries that have a database on the energy quality of housing similar to that of ADEME. By using this database and the EU-SILC (European Union Statistics on Income and Living Conditions) survey, we could then estimate the minimum energy requirements of European household dwellings according to their characteristics and those of their home.

It is regrettable that from 2021, in the SRCV survey, electricity, natural gas and heating bills will be grouped together under housing costs. It would be useful for these expenditure items to appear in future surveys. It is admittedly difficult to include the EPC score for each dwelling, as few owner households seem to know it. Nevertheless, all tenants should have this information, as in France the Energy Performance Diagnostic has been compulsory since 1 July 2007 for all rental properties.

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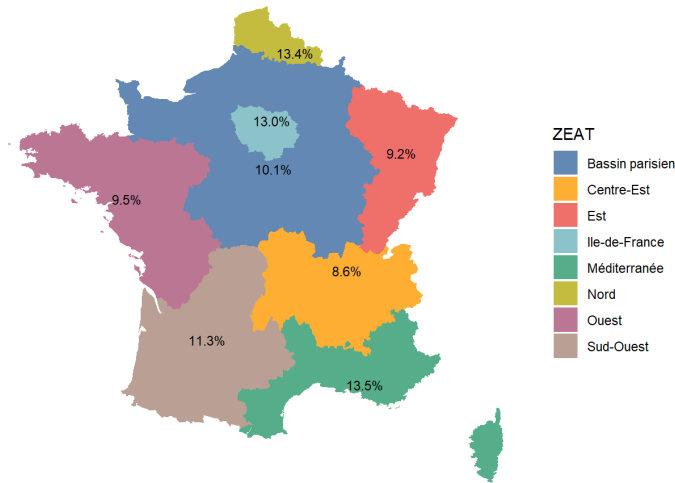
Appendices

A. SUPPLEMENT TO SECTION “DATA AND DESCRIPTIVE STATISTICS”

Poverty in terms of living conditions (Code Dictionary, SRCV). “*Poverty in terms of living conditions is based on the identification of a certain number of deprivations [.] A household is said to be poor in living conditions (variable PCDFVR) according to the definition when it suffers from at least 8 of the 27 deprivations or difficulties relating to insufficient resources, unpaid bills, consumption restrictions and housing difficulties. The 27 deprivations or difficulties used to measure the poverty rate in living conditions according to the INSEE definition:*

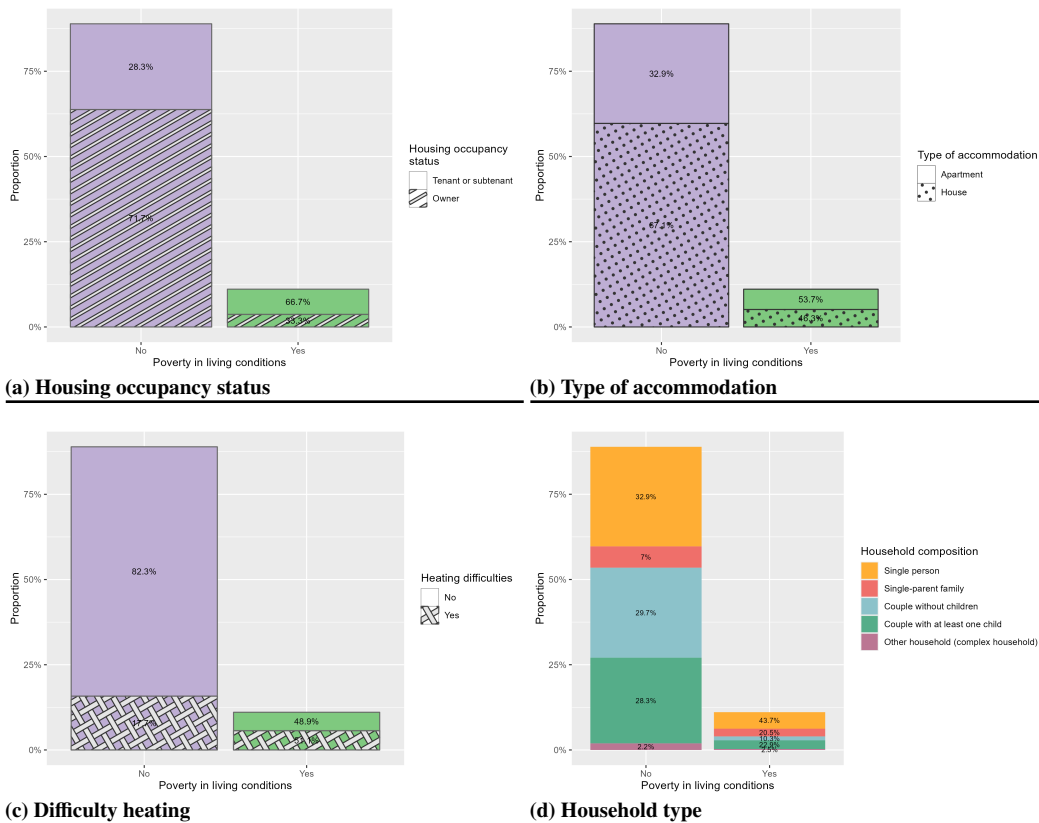
- **Insufficient resources:**
 - high loan repayments in relation to income;
 - having had a bank overdraft in the last 12 months;
 - have insufficient income to balance the household budget;
 - use savings to balance the household budget;
 - have no savings at all;
 - consider their financial situation to be difficult.
- **Late payments:** *having been unable to pay, over the last twelve months:*
 - electricity or gas bills;
 - rent;
 - tax.
- **Consumer restrictions:**
 - keep your home at the right temperature;
 - take a week’s holiday;
 - replace furniture;
 - buy new clothes;
 - buy meat or equivalent;
 - entertaining friends and family;
 - give gifts at least once a year;
 - own two pairs of shoes;
 - don’t make meals for lack of money (at least once in the last two weeks). weeks).
- **Housing problems:**
 - overcrowding;
 - no bathroom;
 - no toilet;
 - no hot water;
 - no heating system; too small;
 - difficulty heating;
 - humidity;
 - noise.”

Figure 11: Share of households with poor living conditions in each region



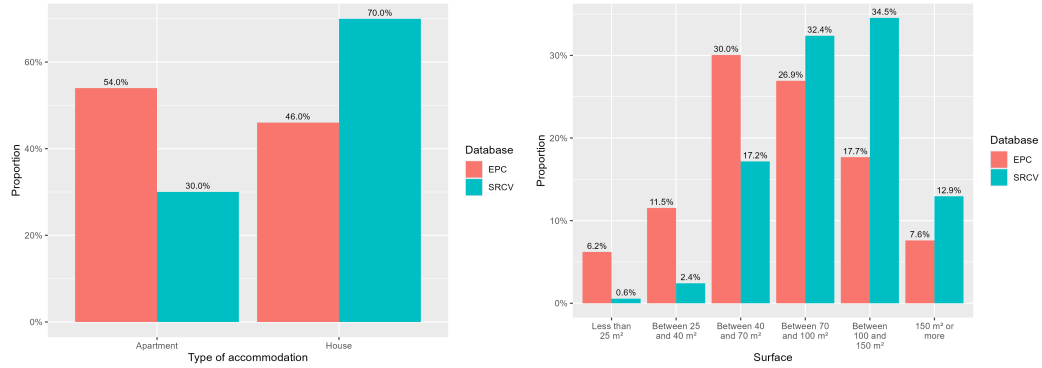
Note: In Île-de-France, 13% of households are poor in terms of living conditions

Figure 12: Profile of poor households in terms of living conditions



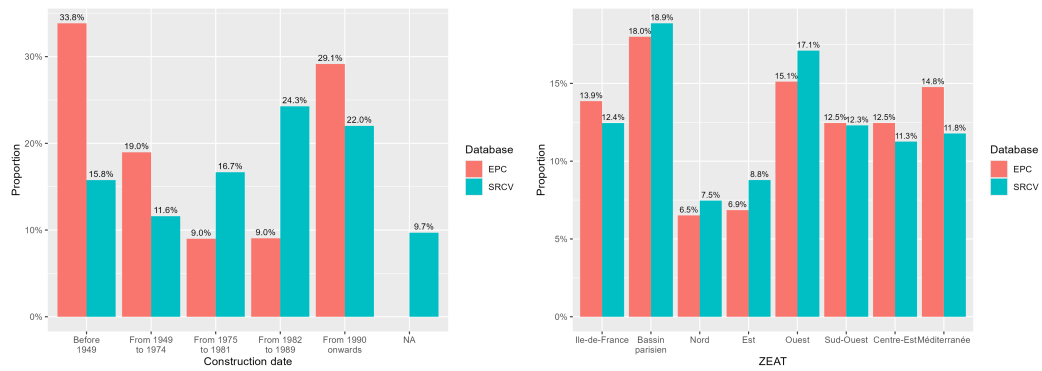
Note: The figures show the profiles of poor households in terms of living conditions according to a) housing tenure status, b) type of dwelling, c) whether or not the dwelling is difficult to heat, and d) type of household.
Source: SRCV2017.

Figure 13: Distribution of dwelling characteristics in the SRCV and EPC databases



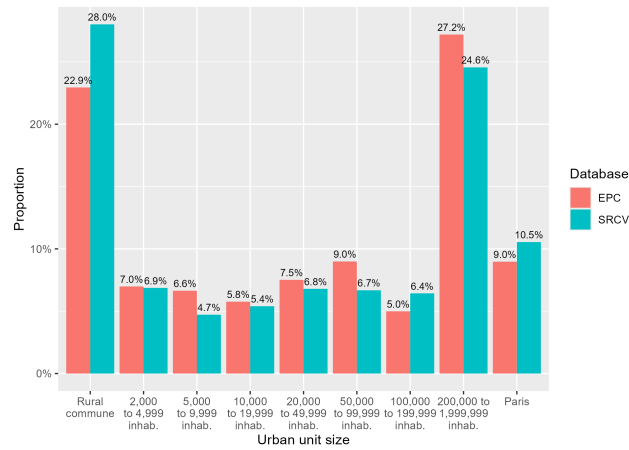
(a) Type of accommodation

(b) Surface



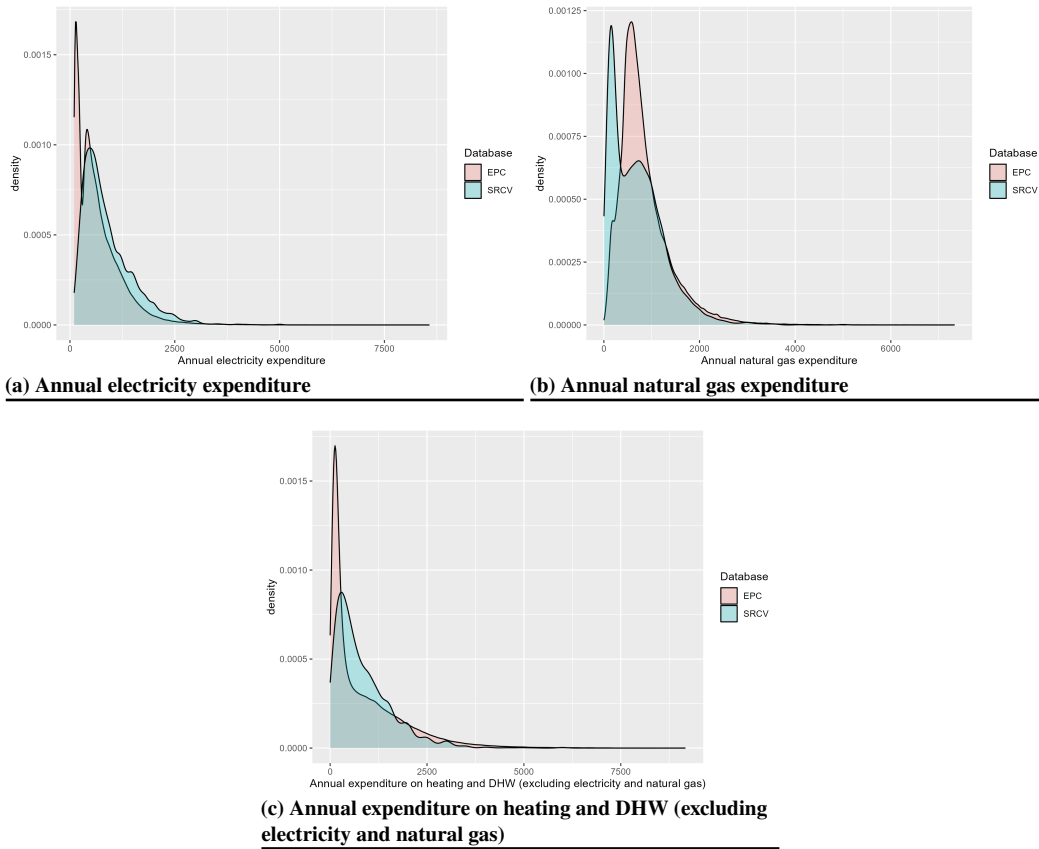
(c) Construction date

(d) ZAT



(e) Urban unit size

Figure 14: Distribution of energy bills in the SRCV and EPC databases



Notes: The dwellings of households in the SRCV and the dwellings in the EPC database whose annual electricity bill is less than €100 have been removed. In SRCV, the amounts declared for gas consumption take into account purchases of gas bottles, which is not the case for the costs estimated in the EPC database: for this graph, we have therefore removed households whose natural gas bill was less than the price of a natural gas subscription in 2017 at the regulated natural gas tariff (Base).

Table 6: Descriptive statistics on energy bills in the SRCV and EPC databases

		Min	Q1	Med	Mean	Q3	Max
Electricity	SRCV	100.0	456.0	720.0	899.5	1200.0	5000.0
	EPC	100.0	247.4	526.2	672.6	908.7	8573.3
Natural gaz	SRCV	96.0	200.0	608.7	701.5	1000.0	5000.0
	EPC	2.2	494.9	709.9	845.5	1055.5	7334.3
Heating & DHW	SRCV	1.0	300.0	600.0	840.1	1200.0	6000.0
	EPC	0.1	150.4	461.5	874.3	1312.0	9168.0

B. SUPPLEMENT TO SECTION “METHODOLOGY”

Table 7: Confusion matrices for the six models on the test sample

Predicted	Observed					
	A-B	C	D	E	F	G
A-B	45	16	7	6	0	1
C	504	4128	463	17	1	1
D	1	1449	20317	988	32	0
E	0	21	1540	20079	1155	20
F	0	0	34	418	6465	447
G	0	0	0	12	148	4079

(a) flats – All electric

Predicted	Observed					
	A-B	C	D	E	F	G
A-B	2 039	102	11	6	1	0
C	150	3370	230	3	0	0
D	0	340	7905	234	2	0
E	0	0	367	9587	296	0
F	0	0	0	55	2699	131
G	0	0	0	1	17	1609

(b) Houses – All electric

Predicted	Observed					
	A-B	C	D	E	F	G
A-B	561	285	5	0	0	0
C	897	5955	1385	12	0	0
D	2	1642	6983	1619	12	1
E	0	6	1063	4899	1077	76
F	0	0	1	160	725	277
G	0	0	1	53	213	347

(c) flats – Electricity & natural gas

Predicted	Observed					
	A-B	C	D	E	F	G
A-B	331	106	0	0	0	0
C	467	5058	231	0	0	0
D	0	554	8 194	556	1	0
E	1	1	478	5 645	707	4
F	0	0	0	109	1480	249
G	0	0	1	23	197	318

(d) Houses - Electricity & natural gas

Predicted	Observed					
	A-B	C	D	E	F	G
A-B	35	9	2	0	0	0
C	164	1047	142	16	2	0
D	0	245	2148	362	22	9
E	0	3	276	1692	305	39
F	0	0	8	99	374	106
G	0	0	0	8	60	200

(e) flats – Electricity & other energy

Predicted	Observed					
	A-B	C	D	E	F	G
A-B	79	18	5	0	0	0
C	436	1 449	362	38	1	0
D	19	1555	7086	1350	298	29
E	0	94	1756	8147	1648	527
F	0	0	75	385	2221	622
G	0	0	0	59	350	1090

(f) Houses – Electricity & other energy

Note: Of the all-electric houses with an EPD E score, 367 were predicted as class D, 296 as class F, and 9,587 were correctly predicted as class E.

B.1 Performance of models according to the EPC label in the test sample

In order to evaluate the performance of the models for each of the EPC labels, we calculate two metrics, which are essential in multi-class classification problems: the *Recall* (or *Sensitivity*), which measures the ability of the model to correctly detect each class, and the *Precision*, which indicates the proportion of dwellings that the model has predicted to be in a certain class and that actually are. As our EPC classes are unbalanced, we also add the *Balanced Accuracy* to give an overall view of the model’s performance. Finally, we display the *Prevalence*, which shows the frequency of each label in the sample. These metrics are defined as follows:

$$Sensitivity = \frac{TP}{TP+FN},$$

$$Precision = \frac{TP}{TP+FP},$$

$$Balanced\ accuracy = \frac{Sensitivity+Specificity}{2},$$

$$Specificity = \frac{TN}{TN+FP}$$

where

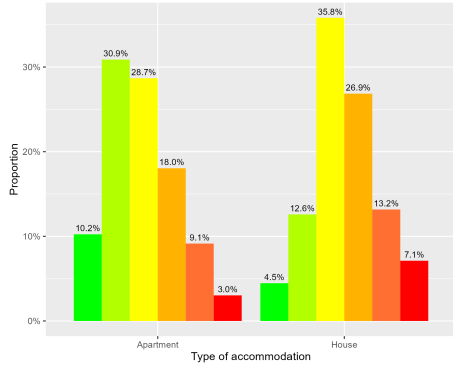
- *TP* (True positives) is the number of dwellings correctly predicted in the class ;
- *FN* (False negatives) is the number of dwellings actually belonging to the class, but predicted in another,
- *FP* (False positives) is the number of dwellings predicted in the class, but which really belong to another,
- *TN* (True Negatives) is the number of dwellings correctly predicted as not belonging to the class.

Table 8: Performance of models according to the EPC label in the test sample

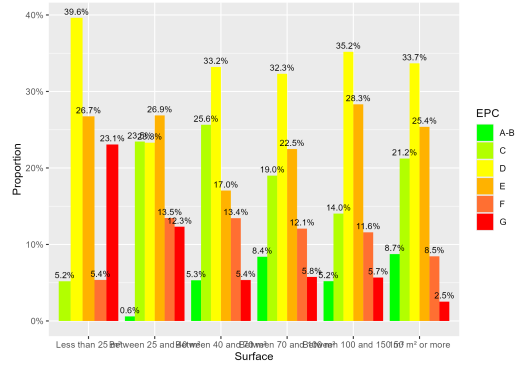
		A-B	C	D	E	F	G
flats All electric	Recall	0.08	0.74	0.91	0.93	0.83	0.90
	Precision	0.60	0.81	0.89	0.88	0.88	0.96
	Balanced Accuracy	0.54	0.86	0.92	0.93	0.91	0.95
	Prevalence	0.01	0.09	0.36	0.34	0.13	0.07
Houses All electric	Recall	0.93	0.88	0.93	0.97	0.90	0.92
	Precision	0.94	0.90	0.93	0.94	0.94	0.99
	Balanced Accuracy	0.96	0.93	0.95	0.97	0.94	0.96
	Prevalence	0.08	0.13	0.29	0.34	0.10	0.06
flats Electricity & natural gas	Recall	0.38	0.75	0.74	0.73	0.36	0.50
	Precision	0.66	0.72	0.68	0.69	0.62	0.57
	Balanced Accuracy	0.69	0.82	0.78	0.81	0.67	0.74
	Prevalence	0.05	0.28	0.33	0.24	0.07	0.02
Houses Electricity & natural gas	Recall	0.41	0.88	0.92	0.89	0.62	0.56
	Precision	0.76	0.88	0.88	0.83	0.81	0.59
	Balanced Accuracy	0.70	0.92	0.93	0.91	0.80	0.77
	Prevalence	0.03	0.23	0.36	0.26	0.10	0.02
flats Electricity & other energy	Recall	0.18	0.80	0.83	0.78	0.49	0.56
	Precision	0.76	0.76	0.77	0.73	0.64	0.75
	Balanced Accuracy	0.59	0.87	0.85	0.83	0.73	0.78
	Prevalence	0.03	0.18	0.35	0.30	0.10	0.05
Houses Electricity & other energy	Recall	0.15	0.47	0.76	0.82	0.49	0.48
	Precision	0.77	0.63	0.69	0.67	0.67	0.73
	Balanced Accuracy	0.57	0.72	0.80	0.81	0.72	0.73
	Prevalence	0.02	0.10	0.31	0.34	0.15	0.08

B.2 Distribution of EPCs according to household and dwelling characteristics

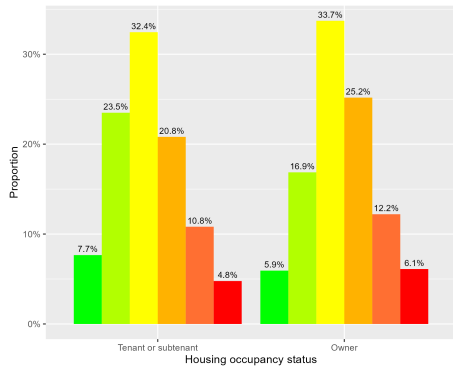
Figure 15: Distribution of EPCs according to household and dwelling characteristics



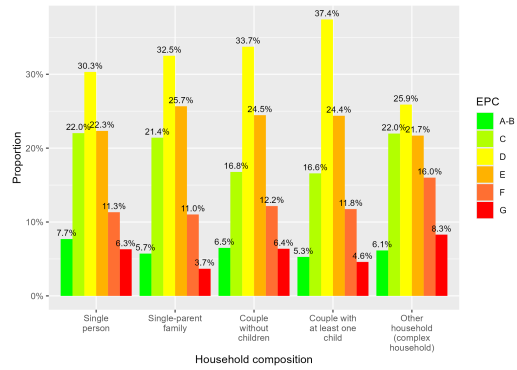
(a) Type of dwelling



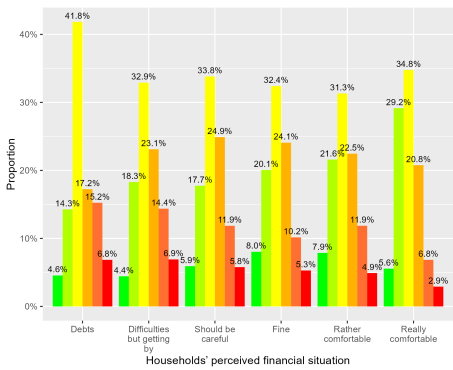
(b) Surface area



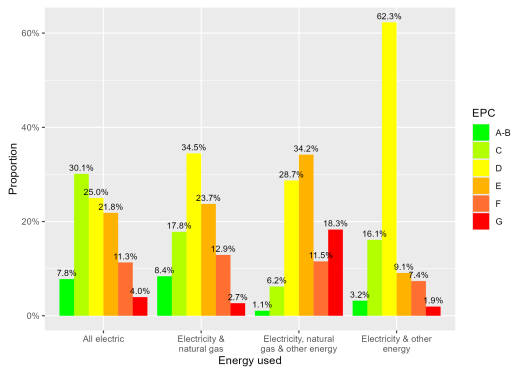
(c) Housing occupancy status



(d) Household type



(e) Household's financial situation



(f) Energy consumption

Table 9: Estimate of the logarithm of the annual energy bill

	All electric	Electricity & natural gas	Electricity & other	Electricity, natural gas & other
(Intercept)	3.8700 ***	4.3823 ***	5.3106 ***	4.6541 ***
EPC (ref: D)				
EPC A–B	-0.8984 ***	-0.9513 ***	-0.9476 ***	-1.0683 ***
EPC C	-0.6565 ***	-0.4388 ***	-0.5912 ***	-0.5174 ***
EPC E	0.3474 ***	0.2995 ***	0.3122 ***	0.2553 ***
EPC F	0.6823 ***	0.6408 ***	0.601 ***	0.7413 ***
EPC G	1.1146 ***	0.8622 ***	0.9941 ***	1.0214 ***
Income quintile (ref: Q1)				
Q2	0.1013 ***	0.117 ***	0.0852 *	0.1676 ***
Q3	0.116 ***	0.2405 ***	0.2294 ***	0.2747 ***
Q4	0.1768 ***	0.2789 ***	0.2958 ***	0.3397 ***
Q5	0.2449 ***	0.3184 ***	0.3554 ***	0.3368 ***
Type of accommodation (ref.: flat)				
House	0.0326	0.0927 ***	0.2309 ***	-0.0344
Surface	0.0019 ***	0.0008 ***	0.002 ***	0.0008 **
log(Surface)	0.6123 ***	0.5221 ***	0.2894 ***	0.4566 ***
Number of rooms	-0.0061	0.0042	0.0075	0.0070
ZEAT (ref: Île-de-France)				
Bassin parisien	-0.0954 **	0.0058	0.0247	0.0661
Centre-Est	-0.0414	0.0330	-0.0161	0.0020
Est	-0.0069	0.0503 *	0.0054	0.0727
Méditerranée	0.0115	0.0045	-0.0072	0.0545
Nord	-0.0890 *	0.0029	-0.006	0.0742
Ouest	-0.0433	0.0386	-0.0855	0.019
Sud-Ouest	-0.0369	0.0288	-0.0360	0.0204
Urban unit (ref: rural commune)				
2,000 to 4,999 inhab	-0.0485 *	0.0246	0.0275	-0.0458 ***
5,000 to 9,999 inhab	-0.0376	-0.0595 ***	0.012	-0.0106
10,000 to 19,999 inhab	-0.0571 **	-0.0302 *	-0.0055	-0.0041
20,000 to 49,999 inhab	-0.0615 **	-0.0372 ***	-0.0484	-0.0072
50,000 to 99,999 inhab	-0.0117	0.0025	-0.0548	0.0162
100,000 to 199,999 inhab	-0.0670 **	-0.0394 ***	0.0245	0.0695 **
200,000 to 1,999,999 inhab	-0.0261	-0.0255 **	0.0246	-0.0055
Paris	-0.1129 **	-0.0302	0.1096 *	0.1049 *
Date of construction (ref: after 1990)				
Before 1949	0.0040	0.0332 ***	0.0182	0.0420 ***
From 1949 to 1974	-0.0316	0.0242 **	-0.0054	0.0051
From 1975 to 1981	-0.0039	0.0092	0.0313	0.0172
From 1982 to 1989	-0.0033	0.0095	-0.006	0.0015
Housing occupancy status (ref: owner)				
Tenant or sub-tenant	0.0013	-0.015	-0.0524	-0.0064
PCDVFR (ref: Non-poor)				
Poor	-0.029	0.009	0.037	0.0159
Type of household (ref: single person)				
Single parent family	0.0849 ***	-0.0016	0.0571	-0.0025
Couple without child	0.0609 ***	0.0291 ***	0.0552 *	0.0248
Couple with at least one child	0.0437	0.0070	0.0765 *	0.0618 **
Other household (complex household)	0.0143	0.0356	0.0642	0.0727 **
Number of working people	-0.0074	0.0014	0.0137	-0.0088
Number of children	0.0020	0.0228 ***	0.0133	0.0114
Inactive in the household (ref: no)				
Yes	-0.0140	-0.0090	0.0293	-0.0171
				.../...

C. SUPPLEMENT TO SECTION “RESULTS”

C.1 Energy bill and change of EPC score

	All electric	Electricity & natural gas	Electricity & other	Electricity, natural gas & other
.../...				
Reference person's age	0.0004	0.0012 ***	0.0015	0.0017 ***
Pierced roof, moisture (ref: no)				
Yes	0.0171	0.0212 *	-0.0344	0.0194
Noise (ref: no)				
Yes	0.0076	-0.0136	-0.0392	0.0014
Difficult/expensive to heat (ref: no)				
Yes	0.0657 ***	0.0455 ***	0.082 ***	0.0574 ***
Dark (ref: no)				
Yes	-0.0003	-0.0167	0.0443	0.0154
Freezer (ref: no)				
Yes	0.025	0.0083	0.0693	0.0063
Washing machine (ref: no)				
Yes	0.0014	0.0059	-0.011	0.0687
Dishwasher (ref: no)				
Yes	0.0494 ***	0.0126	0.0739 ***	0.0411 ***
Number of computers	0.0032	0.0025	-0.0055	-0.0003
Number of televisions	0.0014	0.0094 **	-0.0054	0.0051
Gas bottle (ref: no)				
Yes	-	-0.0441 ***	-	-0.0401 ***
Electricity weight (ref: minus 30%)				
Between 30 and 50%	-	-0.0384 ***	-0.0831 ***	-0.059 ***
Between 50 and 75%	-	-0.0652 ***	-0.2122 ***	-0.0575 ***
Greater than 75%	-	-0.0317 **	-0.2049 ***	0.0062
EPC x income quintile				
EPC A-B x Q2	-0.1918 **	-0.0817 **	0.0467	0.2048
EPC C x Q2	-0.0412	-0.0537 *	-0.0226	-0.1027
EPC E x Q2	-0.0729	-0.0954 ***	-0.0834	-0.1530 ***
EPC F x Q2	-0.0896	-0.0998 ***	-0.0200	-0.1292 **
EPC G x Q2	-0.1000	-0.1668 **	-0.1879	-0.1085 **
EPC A-B x Q3	-0.1602 *	-0.0645 *	0.0043	0.2125
EPC C x Q3	0.0469	-0.1045 ***	0.1528	-0.0854
EPC E x Q3	-0.0903	-0.2225 ***	-0.2246 **	-0.2321 ***
EPC F x Q3	-0.1236 *	-0.2084 ***	-0.2139 **	-0.2174 ***
EPC G x Q3	-0.1923 *	-0.0502	0.2882	-0.1997 ***
EPC A-B x Q4	-0.2433 ***	-0.1232 ***	0.2160	0.0054
EPC C x Q4	0.0221	-0.0523 *	0.1893	-0.1016
EPC E x Q4	-0.1470 ***	-0.2409 ***	-0.2711 ***	-0.265 ***
EPC F x Q4	-0.1460 **	-0.2670 ***	-0.2814 **	-0.2202 ***
EPC G x Q4	-0.1123	-0.0219	-0.5437 ***	-0.2517 ***
EPC A-B x Q5	-0.3635 ***	-0.0703 *	0.2163	-0.2171
EPC C x Q5	-0.0430	-0.0358	0.2318 **	-0.0444
EPC E x Q5	-0.1691 ***	-0.2507 ***	-0.2792 ***	-0.2451 ***
EPC F x Q5	-0.2013 ***	-0.2520 ***	-0.2989 ***	-0.2118 ***
EPC G x Q5	-0.2874 ***	-0.1488 **	-0.3178 *	-0.2308 ***
EPC x Type of accommodation				
EPC A-B x house	-0.3914 ***	0.0773 ***	-0.5595 ***	0.0492
EPC C x house	0.2460 ***	0.0587 ***	-0.0862	0.0395
EPC E x house	0.0507	-0.0132	-0.0618	-0.0229
EPC F x house	0.0180	-0.0550 **	-0.0748	-0.2482 ***
EPC G x house	-0.0271	-0.0462	0.1406	-0.2809
Number of observations	1,934	3,922	814	1,774
Adjusted R²	0.897	0.877	0.792	0.757

Note: P-value : *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

C.2 Matrices of transition expenditure from one EPC to another

Table 10: Energy expenditure transition matrices (2017) - All electric

Q1	A-B	C	D	E	F	Q2	A-B	C	D	E	F
C	-58%					C	-66%				
D	-72%	-34%				D	-77%	-34%			
E	-81%	-53%	-29%			E	-84%	-53%	-29%		
F	-86%	-66%	-49%	-28%		F	-89%	-66%	-49%	-28%	
G	-91%	-78%	-67%	-54%	-35%	G	-93%	-78%	-67%	-54%	-35%
(a) House - First income quintile						(b) House - 2nd income quintile					
Q3	A-B	C	D	E	F	Q4	A-B	C	D	E	F
C	-65%					C	-67%				
D	-77%	-34%				D	-78%	-34%			
E	-83%	-53%	-29%			E	-82%	-46%	-18%		
F	-87%	-62%	-43%	-19%		F	-87%	-61%	-42%	-29%	
G	-91%	-74%	-60%	-44%	-30%	G	-93%	-78%	-67%	-60%	-44%
(c) House - 3rd income quintile						(d) House - 4th income quintile					
Q5	A-B	C	D	E	F						
C	-71%										
D	-81%	-34%									
E	-84%	-45%	-16%								
F	-88%	-59%	-38%	-26%							
G	-92%	-71%	-56%	-48%	-29%						
(e) House - 5th income quintile											
Q1		Q2		Q3		Q4		Q5			
A-B	C	A-B	C	A-B	C	A-B	C	A-B	C		
C	-21%			-33%				-38%			
D	-59%	-48%		-66%	-48%			-68%	-48%		
E	-71%	-63%		-76%	-63%			-74%	-58%		
F	-79%	-74%		-83%	-74%			-81%	-70%		
G	-87%	-83%		-89%	-83%			-90%	-83%		
(f) flat											

Note: columns D, E and F of the transition matrices are the same whether the dwelling is a house or a flat.

Table 11: Energy expenditure transition matrices (2017) - Electricity and natural gas

Q1	A-B	C	D	E	F	Q2	A-B	C	D	E	F
C	-39%					C	-41%				
D	-58%	-32%				D	-62%	-35%			
E	-69%	-49%	-26%			E	-69%	-47%	-18%		
F	-77%	-62%	-44%	-25%		F	-76%	-60%	-38%	-25%	
G	-82%	-71%	-58%	-43%	-24%	G	-81%	-68%	-50%	-39%	-19%

(a) House - First income quintile

Q3	A-B	C	D	E	F	Q4	A-B	C	D	E	F
C	-36%					C	-43%				
D	-61%	-38%				D	-63%	-35%			
E	-64%	-43%	-7%			E	-65%	-39%	-6%		
F	-73%	-58%	-31%	-26%		F	-73%	-53%	-27%	-23%	
G	-83%	-74%	-58%	-54%	-38%	G	-84%	-73%	-58%	-55%	-42%

(b) House - 2nd income quintile

(c) House - 3rd income quintile

Q5	A-B	C	D	E	F
C	-43%				
D	-61%	-32%			
E	-63%	-35%	-5%		
F	-72%	-51%	-28%	-25%	
G	-81%	-66%	-51%	-49%	-32%

(d) House - 4th income quintile

(e) House - 5th income quintile

Q1	A-B	C	Q2	A-B	C	Q3	A-B	C	Q4	A-B	C	Q5	A-B	C
C	-40%		C	-42%		C	-38%		C	-44%		C	-44%	
D	-61%	-36%	D	-64%	-39%	D	-64%	-42%	D	-66%	-39%	D	-64%	-36%
E	-71%	-52%	E	-71%	-50%	E	-66%	-46%	E	-68%	-42%	E	-66%	-39%
F	-80%	-66%	F	-79%	-64%	F	-77%	-62%	F	-77%	-58%	F	-76%	-56%
G	-84%	-73%	G	-82%	-70%	G	-85%	-75%	G	-86%	-74%	G	-82%	-68%

(f) flat

Table 12: Energy expenditure transition matrices (2017) - Electricity and other

Q1-Q2	A-B	C	D	E	F	Q3	A-B	C	D	E	F
C	-60%					C	-60%				
D	-78%	-45%				D	-78%	-45%			
E	-84%	-59%	-27%			E	-80%	-49%	-8%		
F	-88%	-70%	-45%	-25%		F	-85%	-62%	-32%	-26%	
G	-92%	-80%	-63%	-49%	-33%	G	-92%	-80%	-63%	-60%	-46%

(a) House - 1st and 2nd income quintile

Q4	A-B	C	D	E	F	Q5	A-B	C	D	E	F
C	-60%					C	-68%				
D	-78%	-45%				D	-78%	-30%			
E	-79%	-47%	-4%			E	-79%	-32%	-3%		
F	-84%	-60%	-27%	-24%		F	-84%	-48%	-26%	-24%	
G	-86%	-65%	-36%	-34%	-12%	G	-89%	-65%	-49%	-47%	-31%

(b) House - 3rd income quintile

(c) House - 4th income quintile

Q1-Q2	A-B	Q3	A-B	Q4	A-B	Q5	A-B
C	-30%	C	-30%	C	-30%	C	-44%
D	-61%	D	-61%	D	-61%	D	-61%
E	-72%	E	-64%	E	-63%	E	-62%
F	-79%	F	-74%	F	-72%	F	-71%
G	-86%	G	-86%	G	-75%	G	-80%

(d) House - 5th income quintile

(e) flat

Table 13: Energy expenditure transition matrices (2017) - Electricity, natural gas and other (households)

Q1	A-B	C	D	E	F
C	-42%				
D	-66%	-40%			
E	-73%	-54%	-23%		
F	-79%	-64%	-39%	-21%	
G	-88%	-79%	-64%	-54%	-41%

Q2	A-B	C	D	E	F
C	-42%				
D	-66%	-40%			
E	-69%	-46%	-10%		
F	-76%	-59%	-31%	-23%	
G	-86%	-76%	-60%	-56%	-42%

Q3	A-B	C	D	E	F
C	-42%				
D	-66%	-40%			
E	-66%	-42%	-2%		
F	-74%	-55%	-24%	-22%	
G	-85%	-74%	-56%	-55%	-42%

Q4	A-B	C	D	E	F
C	-42%				
D	-66%	-40%			
E	-65%	-40%	1%		
F	-74%	-55%	-24%	-25%	
G	-84%	-72%	-54%	-54%	-39%

Q5	A-B	C	D	E	F
C	-42%				
D	-66%	-40%			
E	-66%	-41%	-1%		
F	-74%	-55%	-25%	-24%	
G	-84%	-73%	-55%	-54%	-40%

Note: The only differences between houses and flats concern the EPC F score and are not presented here for the sake of brevity.

D. SUPPLEMENT TO SECTION 5

D.1 Electricity tariffs by option and contracted power

The amount of electricity a household needs depends on its consumption profile. Several criteria are taken into account when assessing the power required by a home: its size, the type of heating and appliances used. We assume that the power is 3 kVA for dwellings of less than 50 m² that are not heated with electricity; 6 kVA for dwellings of less than 80 m² heated with electricity or for dwellings of more than 80 m² heated with gas; 9 kVA for dwellings of 80 to 150 m² heated with electricity; and finally 12 kVA for dwellings of more than 150 m².⁴³

The Base option applies an identical electricity price throughout the year, whereas with the The peak/off-peak option (HP/HC option), the price differs according to the time of day: one rate during peak hours, another during off-peak hours. The HP/HC option is therefore suitable for consumers who can switch on their most energy-hungry appliances during off-peak hours. It is recommended for homes heated by electricity and with a hot water tank. Conversely, the Base option is aimed at households with non-electric heating or a gas water heater, as well as small consumers.⁴⁴ We therefore assume that all households consuming gas or with a meter capacity of 3 kVA have chosen the Base option and that all the others have chosen the HP/HC option.

The HP/HC option is generally considered profitable when 30% to 40% of consumption occurs during off-peak hours (40% according to HelloWatt).⁴⁵ We therefore calculate the variable part for the HP/HC option on the assumption that 40% of household consumption occurs during off-peak hours (at €0.127 incl. VAT/kWh) and 60% during peak hours (at €0.156 incl. VAT/kWh).

Thus, for 2017, the electricity prices are summarized in Table 14.

D.2 Natural gas tariffs by consumption class (2017)

There are four classes of natural gas consumption: Base, B0, B1 and B2i. These consumption classes designate consumption bands and determine the price per kWh and the natural gas subscription.⁴⁶

⁴³According to the following sources: fournisseurs-electricite.com and particuliers.engie.fr.

⁴⁴See fournisseurs-electricite.com and lesfurets.com

⁴⁵See particuliers.engie.fr and ouest-france.fr

⁴⁶See fournisseurs-electricite.com

Table 14: Electricity tariffs by option and contracted power (2017)

Base option			HP/HC option		
Contracted power	Fixed part (€)	Variable part (€/KWh)	Contracted power	Fixed part (€)	Variable part (€/KW)
3 kVA	54.42	0.1503	3 kVA	-	-
6 kVA	88.39	0.1503	6 kVA	100.37	0.1444
9 kVA	117.17	0.1503	9 kVA	117.37	0.1444
12 kVA	180.08	0.1503	12 kVA	182.70	0.1444

Source: Regulated residential electricity tariffs (incl. VAT) in January 2017 according to data.gouv.fr.

- Households that consume no more than 1,000 kWh of natural gas per year (cooking use only) are in class 'Base'.
- The B0 tariff is for households that use gas for domestic hot water and another energy source for heating, and whose consumption is between 1,001 kWh and 6,000 kWh per year.
- The B1 tariff corresponds to natural gas consumption of between 6,000 and 30,000 kWh per year, and applies to households using gas for heating, hot water and cooking.
- Finally, the B2i tariff applies to co-ownerships whose annual consumption does not exceed 150,000 kWh.

To assign a natural gas consumption class to SRCV households, the consumption threshold between the B0 and B1 tariffs being 6,000 kWh per year, we calculate the corresponding B0 tariff bill. We then assume that all households with a bill lower than or equal to this are on the Base or B0 tariff (natural gas prices being the same, see Table 15), and that all those with a bill higher than this are on the B1 tariff.

The price of natural gas also varies according to the tariff zone, defined on the basis of the distance between a dwelling and the distribution zone. We assume that all homes are in zone 2.

When a household's annual expenditure on gas is less than the fixed part, it is considered not to have taken out a natural gas contract but to be buying bottles of gas. According to INSEE, in January 2017, the average price of a 13 kg bottle of compressed butane gas, without deposit, was €31.76.⁴⁷

Table 15: Natural gas tariffs by consumption class (2017)

Tariff	Fixed part (€)	Variable part (€/kWh)
Base/B0	95.49	0.0751
B1	238.15	0.0531

Source: Regulated natural gas tariffs (incl. VAT) on the GRDF network for residential customers in 2017, according to data.gouv.fr

⁴⁷Source insee.fr.