The pitfall of a single indicator to rule them all? Evaluation of the performance of the French housing stock in the light of various indicators

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Abstract

The energy performance of a building can be assessed using various indicators that will not give the same score. This study evaluates the performance of the French housing stock using several indicators based either on the energy level at which energy consumption is assessed (primary, final or useful), or on greenhouse gas emissions, or on the energy bill.

An indicator calculated at each of the 3 stages of the energy chain allows a sequential approach to building performance: the "useful energy" level measures the performance of the thermal insulation of the envelope, the "final energy" level adds the consideration of the performance of equipment providing energy services, and the "primary energy" level combines the performance of energy sources.

The paper focuses on the comparison of French (DPE, Diagnostic de Performance Energétique, French Energy Performance Certificate) and UK (EPC, Energy Performance Certificate) indicators. The European Union has widely disseminated the EPC for housing through the EPBD 2002/91/EC (Energy Performance of Buildings Directive, then revised in 2010 and 2018). Originally, with the exception of the number of seven energy classes, Member States were free to choose the details of the calculations of their "national" EPC. Most European countries – including France – have chosen an absolute value scale to define performance ranges and a primary energy indicator for energy performance. The United Kingdom has chosen an indicator related to the energy bill and expressed on a standard scale.

The impact of the different approaches proposed for evaluating the performance of the French housing stock is analysed. The relevance of the indicators is discussed according to two criteria: the nature of the actors to whom the evaluation is addressed (households, planners, politicians), and the objectives of the actions that the evaluation should guide (improving housing performance, reducing energy consumption, Green House Gas emissions (GHG), or energy bills).

The results are put into perspective with the recent revision of the EPBD directive requiring that the energy performance of a building be expressed by means of a primary energy consumption indicator.

Introduction: which indicators to choose?

A first simple idea is to consider that a dwelling is not very efficient if it consumes a lot of energy. Many European directives are aimed at reducing inefficient buildings (EED, EPBD) and are transposed at a national level through numerous laws. The question is then "what kind of energy metrics" or rather "at what energy level"? The logic closest to the occupant of the dwelling is that of the final energy (FE) level (meter), i.e. the energy delivered to the consumer of energy services and paid for by the consumer. However, the majority[1] of European regulatory energy efficiency indicators are currently expressed with the primary energy (PE) level, i.e. at a level broader than that of the building because it integrates the upstream energy produc-

1. The regulations for the renovation of buildings express requirements "per building component'" but these are not mandatory recommendations for the vast majority of renovations.

tion chain. Primary energy indicators are therefore taken from a national perspective (resources, energy independence and trade balance). This is the case of the French Energy Performance Certificate (DPE, Diagnostic Performance Energétique) and the French thermal regulation for new buildings (RT, Réglementation Thermique).

Given the importance of fuel poverty among households in Europe, the objective of energy performance is to make energy services as cheap as possible. The energy performance of the dwelling could then be expressed by its energy bill (i.e. in monetary terms), which is therefore a 3rd possible indicator.

As one of the objectives of European energy policy is to reduce greenhouse gas (GHG) emissions, it can also be considered that energy performance of a building should be measured by its GHG emissions, hence a fourth indicator.

Finally, when it comes to building concrete action programmes to improve the energy performance of the housing stock, public authorities often set themselves the objective of eliminating "thermal wreck", i.e. poorly insulated housing. To do this, it is necessary to define an indicator representative of the level of thermal insulation of the dwelling, it is the 5th indicator. Existing work has already described other possible types of indicators [Tuominen and al, 2011]. The paper is limited to these 5 indicators.

In France, the DPE [DPE 2012] is expressed according to 2 of them: the normative primary energy consumption (PE) and the normative GHG emissions (CO_2). In our study, "normative final energy consumption" (FE) and "the corresponding energy bill" (economic indicator) are added. Finally, the "Ubat" coefficient (average overall thermal transmission of the envelope surface area) is chosen as an indicator of the level of building thermal insulation. The "Ubat" measures the heat losses of the walls of the dwelling[2] per m² of wall. It is expressed in W/(m².°K). The lower the "Ubat" is, the better the insulation of the housing.

In the United Kingdom, the EPC [EPC 2012] measures the energy performance of housing according to an economic performance criterion (theoretical energy invoice) and a climate criterion (normative GHG emissions). Unlike the French case, the indicators are expressed on a standard 1–100 scale (the higher the index, the stronger the housing performance). This defines two different indicators from the French indicators, i.e. a total of seven indicators to estimate the performance of the French housing stock.

This paper will focus on the impact of the seven different indicators proposed for evaluating the performance of the French housing stock. The initial objective of the EPC is to inform the future occupant (owner or tenant) of a dwelling of its energy and environmental performance and of the measures that can be taken to improve it. More recently, EPC is also used to target buildings that need to be renovated as a priority. In France, it is planned to make it mandatory to renovate homes labelled F or G from 2025. In the light of these latest decisions, it is interesting to look at the impact of the choice of EPC as a criterion for targeting housing for renovation.

In the first section the paper describes briefly the "French" indicators, including DPE's ones and in the second section, the indicators of the UK EPC (the objective is to compare indicators, and not calculation methodology or building stock). In the light of these latest decisions, it is interesting to look at the impact of the choice of EPC as a criterion for targeting housing for renovation. A third section will present the performance of the building stock according to the EPC and other indicators from different points of view:

- Do the different indicators define the same overall level of performance for the French housing stock?
- Do the different indicators define the same types of housing as performing or non-performing (housing being characterized by type, heating energy and age)? Particular attention will be paid to F and G-rated housing, which will be subject to mandatory renovation.

In the last section, the paper will consider if using the EPC as a basis to set mandatory renovation is relevant or not. The paper will introduce a discussion about what indicators can be used to support policy design depending on the objectives of the policy.

The "French" indicators

For the five French indicators, the study consider the three end-uses taken into account in the French DPE (space heating, domestic hot water – DHW – and air conditioning). The DPE is a performance based indicator based on a simplified building energy modelling, it is not intended to estimate actual housing consumption, which is often significantly different and lower than the DPE assessed consumptions for C to G buildings [Cayre et al. 2011]. The five indicators are therefore all calculated with the same normative behaviour of the occupants and the same normal local climate as used in the calculation of the DPE. They are standardized (per m² of living space in the dwelling) in order to cancel the (significant) size effect. The data required for the assessment of the performance of the building stock come from the Phebus survey [Phebus 2013] which provides the 2 indicators of the French DPE and all the intermediate variables necessary for their calculation for a sample of 2,300 dwellings representative of the French stock in 2013.

For the calculation of the theoretical energy bill, the energy prices (including VAT and fix part[3]) are those of the Pegase database [Pegase 2017]. The price of "other" energy is high because this segment is composed of households heated with LPG (Liquefied Petroleum Gas) and fuel oil, which are often poorly captured by the Phebus survey; or using a lot of auxiliary heating with liquid fuel stoves, which is very expensive.

For GHG emissions, the emission factors used are those of the French DPE [DPE 2012] for DPE uses, supplemented by those of the ADEME carbon database (LTECV frame of reference, [ADEME 2018]) for lighting and ventilation consumptions that are required to calculate the UK EPC[4].

2. But not energy losses related to ventilation.

3. The prices correspond to tariffs for households heated with the energy in question, therefore having significant consumption volumes for this energy. Compared to a household that is heated with gas, a household heated with another energy will have a higher rate per kWh of gas consumed (same for electricity).

4. There are several emission factors for electricity because the CO_2 content of electricity is different depending on the type of end-use.

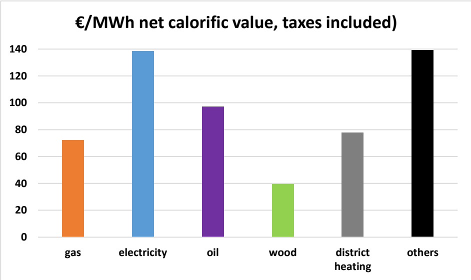


Figure 1. Energy prices (€/MWh, taxes included). (Source: Pegase.)

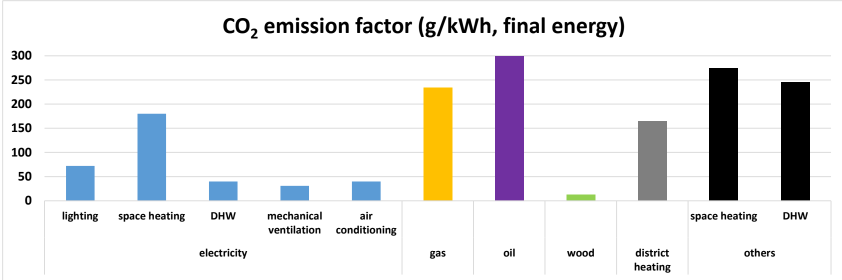


Figure 2. CO_2 emission factors (g/kWh). (Source: DPE, ADEME.)

Table 1. Definition of the performance classes of the five French indicators (kWh_{pe}/m^2 and gCO_2/m^2 source: DPE, kWh_{fe}/m^2, $W/m^2.K$, $€/m^2$. (Source: DPE and own definitions.)

	DPE energy (FR) (kWhpe/m².year)	final energy (FR) (kWhfe/m².year)	Ubat (W/(m².°C)		energy bill (€/m².year, VAT included)
A	≤ 50	≤ 50	U < 0,3	exceptional	≤ 5
B	51 - 90	51 - 90	0,3 ≤ U < 0,4	excellent	5 < _ ≤ 10
C	91 - 150	91 - 150	0,4 ≤ U < 0,75	new RT 2005	10 < _ ≤ 15
D	151 - 230	151 - 230	0,75 ≤ U < 0,95	new 1990 - RT 2000	15 < _ ≤ 20
E	231 - 330	231 - 330	0,95 ≤ U < 1,4	new 1974 - 1989	20 < _ ≤ 30
F	331 - 450	331 - 450	1,4 ≤ U < 1,8	insulation < 1974	30 < _ ≤ 40
G	> 450	> 450	U ≥ 1,8	non-insulated	> 40

	DPE climate (FR) (g CO2/m².year)
A	≤ 5
B	6 - 10
C	11 - 20
D	21 - 35
E	36 - 55
F	56 - 80
G	> 80

As for all European EPCs, the indicators are expressed in seven performance classes limited with absolute values. For final energy consumption, the classes are the same as for primary energy consumption. For the "Ubat", seven performance classes are defined, ranging from "uninsulated" to "exceptional insulation" with intermediate classes corresponding to the level of thermal insulation required in the successive building codes for new housing built between 1974 and 2005.

The "UK" indicators

In a context of significant fuel poverty and strong ambitions to reduce GHG emissions, the United Kingdom has chosen to express the energy performance of their housing stock in terms of theoretical energy bills and normative CO_2 emissions. The UK EPC takes into account 2 additional uses compared to the French DPE: lighting and electrical consumption of mechanical ventilation equipment (when relevant). Finally, unlike the French DPE, the normative heating consumption is calculated for all dwellings with the same national climate regardless of their location due to higher homogeneity in climate conditions in UK).

In this study, to calculate the indicators of the UK EPC, the normative heating consumptions of the French DPE in final energy are used (available in Phebus database). They are then standardised on the national climate as for the UK EPC. The consumption of DHW and air conditioning (if the dwelling is equipped) of the French DPE is added. Same for the conventional consumption of lighting (3 $kWh_{fe}/year.m^2$) and those of mechanical ventilation motors (if the dwelling is equipped and according to the type of dwelling and the type of ventilation described in Phebus). Mechanical ventilation consumption is based on the spreadsheet of the French EEO system (Energy Efficiency Obligation, [ATEE 2009]). The breakdown of the final energy consumption of the five uses between the different energies concerned makes it possible to allocate differentiated energy prices to them. The prices of the energies used are the same as those of the French economic performance indicator (see Figure 1). Finally, these theoretical annual energy bills are transformed into relative values (scale 1–100) according to the UK SAP methodology [SAP 2012] taking into account the surface area of the dwelling.

Table 2. Definition of the performance classes of the two UK indicators. (Source: SAP.)

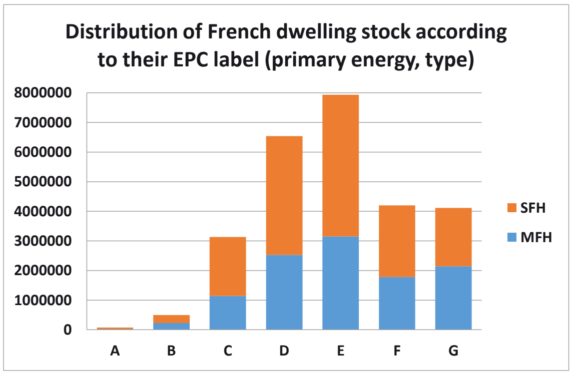
	EPC energy (SAP rating 0 - 100)
A	≥ 92
B	81 - 91
C	69 - 80
D	55 - 68
E	39 - 54
F	21 - 38
G	≤ 20

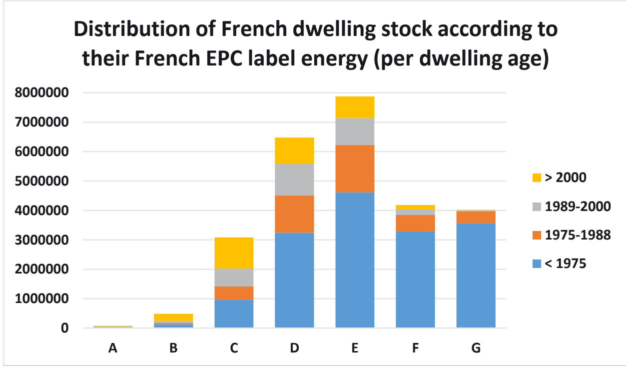
	EI CO2 rating (1 - 100)
A	≥ 92
B	81 - 91
C	69 - 80
D	55 - 68
E	39 - 54
F	21 - 38
G	≤ 20

For the climate (CO_2) indicator of the UK EPC, the normative consumption of each energy consumed for each energy use is multiplied by the emission factors of the French DPE (see Figure 2). As with the theoretical bill, these normative emissions are then transformed into standard values (1–100).

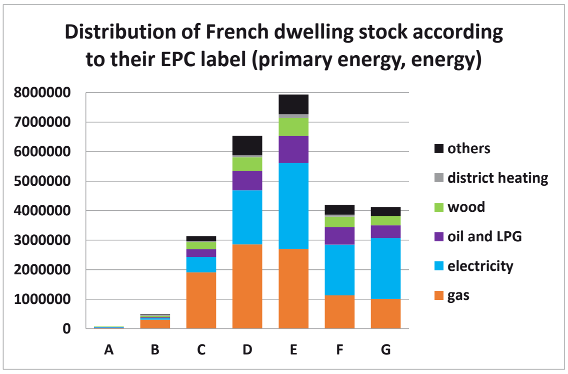
Comparative performances of the French housing stock according to the seven indicators

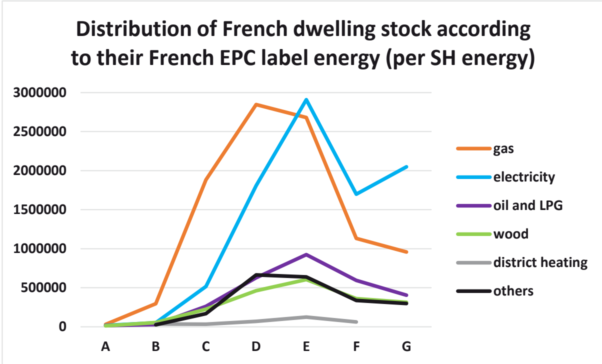
For each of the selected indicators, the distribution of housing stock is calculated according to the seven labels and the share of the stock labelled F and G (i.e. the least efficient according





Figures 3a and 3b. Number of French dwellings according to their French DPE label – primary energy (3a: type of housing, 3b: construction period). (Source: own calculation.)





Figures 4a and 4b. Number of French dwellings by DPE primary energy label per heating energy. (Source: own calculation.)

to the indicator used) is described on 3 criteria: type of housing (SFH Single Family Housing/MFH Multi Family Housing), construction period and space heating energy. For example, to compare the performance of housing types, the study considers the share of F and G buildings in the total SFH stock and the share of F and G buildings in the total MFH stock.

THE "ENERGY" INDICATOR OF THE FRENCH DPE: PRIMARY ENERGY ($KWH_{PE}/(M^2.YEAR)$)

According to the PE indicator, the majority of French dwellings (55 %) have a D or E label. Almost a third (31 %) of the dwellings are labelled F or G. The stock of MFH is globally less efficient than the SFH one because the proportion of their total stock captured in F or G is higher than that for SFH. Figure 3a shows that apartments are older than single-family homes, so they are probably less well insulated, which could explain their lower average performance. Analysis with the Ubat indicator will help to clarify this point.

The distribution by construction period may be surprising: although the proportion of dwellings built before 1975 (i.e. before any energy performance requirement) is very much in the majority in classes F or G, there are also old dwellings in the high-performance classes. It can be assumed that these dwellings have been renovated, and therefore thermally insulated. Again, the "Ubat" indicator will tell it.

The distribution of classes according to the main heating energy is linked to the choice of primary energy for the performance indicator. In France, the two main sources of heating energy are gas and electricity, which (in 2013, date of the Phebus survey) heated 37 % and 34 % of households respectively. With DPE expressed in primary energy[5], dwellings heated by electricity have the largest share of the total stock rated in F or G (41 % for electricity and 21 % for gas). The other energies are distributed in a more balanced way between the different labels. The "Ubat" and "final energy" indicators will make it possible to check whether this classification corresponds to the thermal and energy performance of the dwellings or to the energy supply chain.

THE "FINAL ENERGY" INDICATOR IN KWHFE/(M^2.YEAR)

The indicator at the "final energy" (FE) level (i.e. after the meter) is an indicator that corresponds to the scope of the building because it makes it possible to estimate the cumulative performance of the building (thermal insulation and ventilation losses) and that of the equipment (via their efficiency) providing energy services. By keeping the same class boundary definitions as those on the primary energy label, the final energy indicator gives a distribution a distribution that is positively shifted compared to that obtained with the PE indicator. Only 16 % of the stock is in F or G (against 31 % with the PE label). The shift towards more efficient labels is because the final electricity consumption is not multiplied by the PE/FE conversion factor. The impact is not limited to homes heated with electricity alone, because this energy is also present in many homes

5. In France, the final electricity consumption is multiplied by a factor of 2.58 to be calculated as primary energy.

heated with wood or fuel oil via the electric DHW used by half of all French homes.

Unlike the PE classification, there is little difference in the F and G shares between MFH and SFH. There is no dominant explanation for this rebalancing.

The conclusions on the building age distribution are also very similar, but there are significant differences for the distribution according to heating energies. The distribution of dwellings heated by fossil fuels changes very little because the PE/FE conversion factor is 1 for fossil fuels. The impact is therefore limited to the electricity consumption of these dwellings for DPE energy end-uses. The majority of gas-heated dwellings remain in C, but those heated with electricity are upgraded by two labels (from E to C). For extreme labels, there is an inversion between gas and electricity energies compared to the primary energy label: 20 % of gas-heated dwellings are always labelled in F or G compared to 3 % for electricity.

THE THERMAL INSULATION INDICATOR OF THE BUILDING: THE UBAT (W/(M^2.K))

The distribution of dwellings according to their level of thermal insulation (e.g. Ubat) is very different from that obtained with the PE and FE indicators. The largest numbers are provided by classes C and G which are almost equally divided (24 %) and to a lesser extent in E. Class C includes new housing built since 2000, and older housing (including pre-1975) that has been renovated. Classes F and G (thermal insulation worse than that required by the first thermal regulation of 1975) are old dwellings that have never been renovated. They represent a very large part of the stock (39 %). On the other hand, housing in A and B (excellent and exceptional insulation) is very much in the minority (2 %).

Figure 8b shows that dwellings built before 1975, and therefore not initially isolated, are divided into 2 populations: at the top of the graph (high U values), the non-renovated buildings; at the bottom of the graph, the renovated buildings, which have a level of thermal insulation close to that of the current regulations. The construction period is often used as a proxy for the level of thermal insulation to identify the dwellings to be renovated. The “Ubat” indicator shows this proxy is relevant in just over half of the cases. Due to progress in buildings’ renovation, it will become less and less relevant in the future.

There is a large difference between MFH and SFH. MFH make up the vast majority of the G label: 61 % of apartments are in F or G (23 % for SFH). This result may seem counter-intuitive but it can be explained. MFHs are on average older than SFHs and their external walls include a higher proportion of glazing, which, even if replaced by high-performance glazing, will never be as effective as an opaque wall. In France, there are also about 1.8 million “Haussmannian” style MFHs whose heritage value limits the possibilities of thermal insulation. MFHs are also more often occupied by tenants who have less interest in investing in renovating their housing than owner-occupiers. Finally, even if the MFH is occupied by an owner, he cannot decide alone on all types of renovation (e.g. external wall insula-

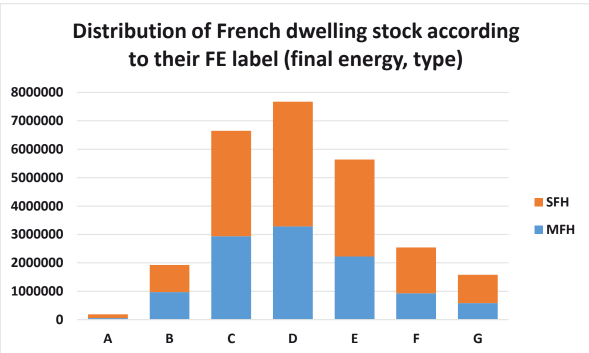


Figure 5. Number of French dwellings according to their final energy label.

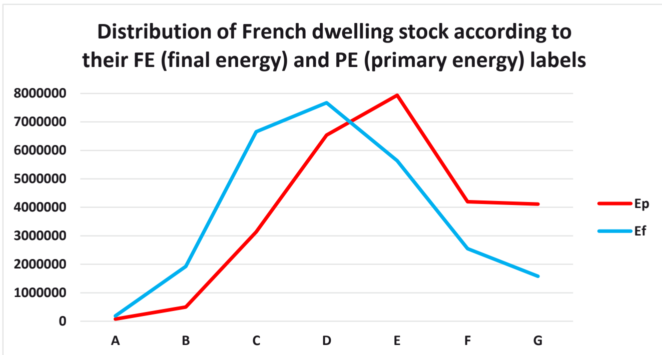
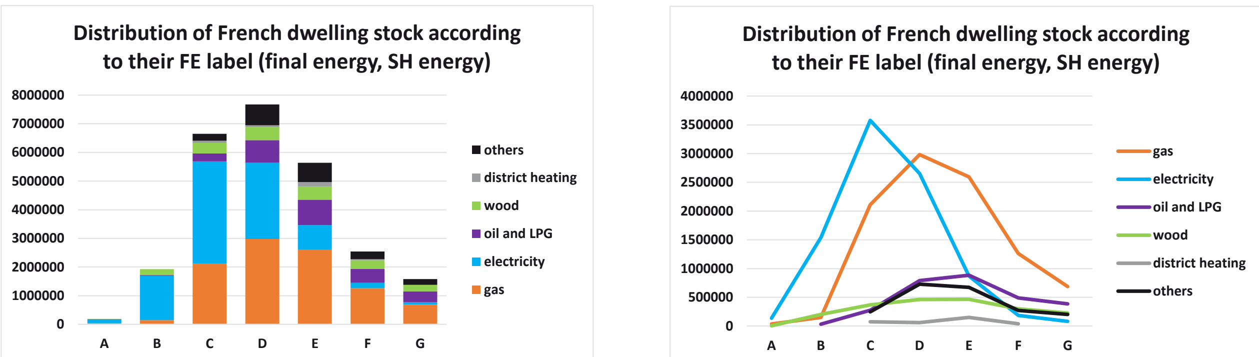


Figure 6. Number of French dwellings according to their primary and final energy label.

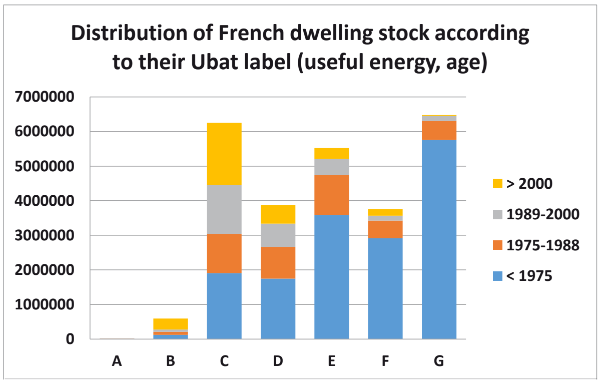


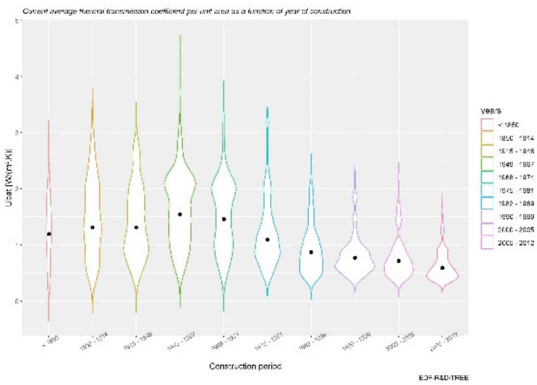
Figures 7a and 7b. Number of French dwellings by final energy label and by heating energy.

tion). Some of the renovation measure requires the agreement of the co-ownership, which can be complex.

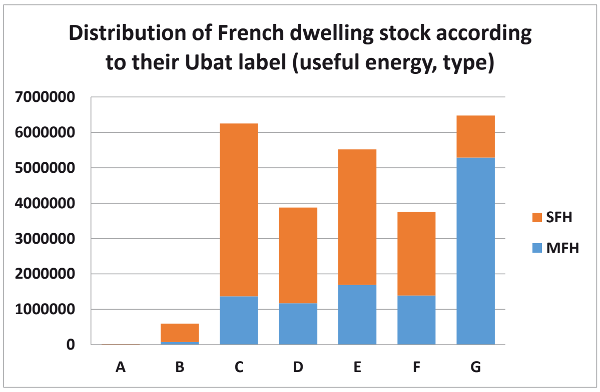
All the performance indicators the paper is studying are standardized (per m² of living space or wall area) and should not hide the fact that even if MFHs are less insulated than SFHs, they consume less space heating energy because they are almost twice as small as SFH. The total energy consumption of the dwelling (and the resulting energy bill) may therefore be lower than that of a better-insulated SFH, which is an additional reason to renovate SFH rather than MFH. Since the SFH stock consumes much more than that of MFH, SFHs are a priority target for energy efficiency policies. Although on average better insulated than MFH, there are still more than 3.5 million SFH (26 %) with almost no insulation (classes F or G).

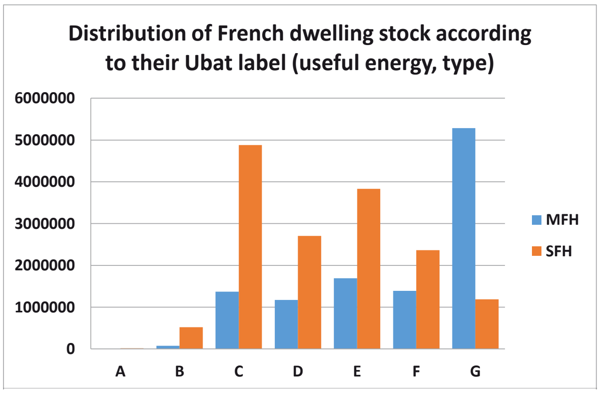
The distribution of Ubat according to space heating energy shows certain homogeneity even if the dominant class is label C for wood and electricity, and label G for "other" energies and gas. The age effect is a major factor: dwellings heated by electricity (and to a lesser extent, those heated with wood) are more recent than others; gas-heated dwellings are numerous in the period 1949–1974 (massive post-war reconstruction and before the first thermal regulation). Figure 8b shows that dwellings from this period have been poorly renovated. Another rea-



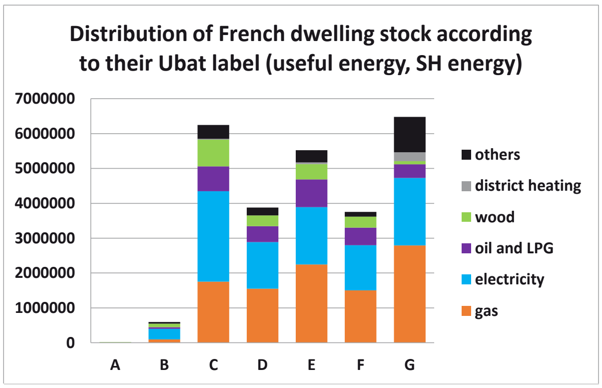


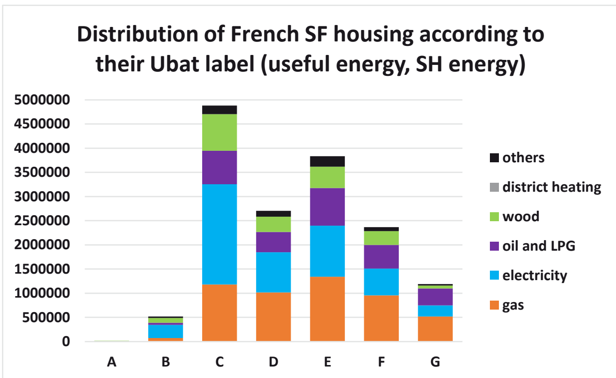
Figures 8a and 8b. Number of French dwellings by Ubat and construction period (8a: four age classes, 8b: eleven age classes).





Figures 9a and 9b. Number of French dwellings according to their Ubat and type of housing (own calculation).





Figures 10a and 10b. Number of French dwellings according to their Ubat and space heating energy (10a: whole stock, 10b: single family houses only).

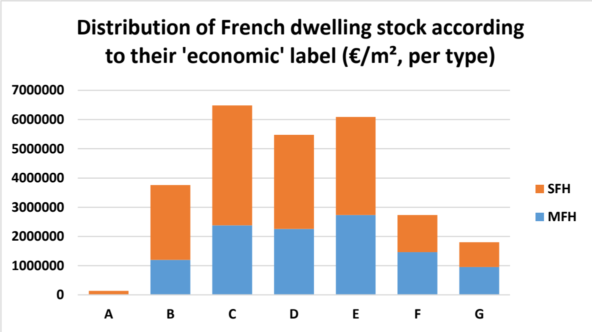
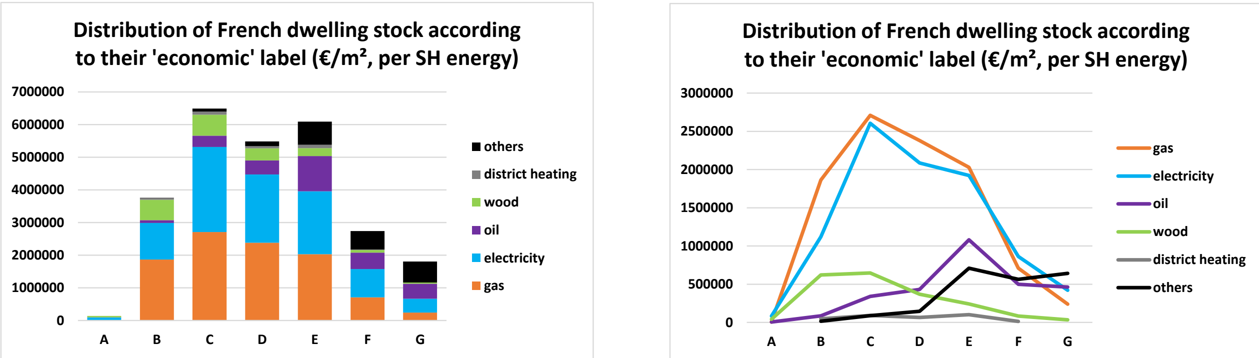


Figure 11. Number of French dwellings by energy bill (by type of housing).



Figures 12a and 12b. Distribution of French dwelling sub stocks defined by their SH energy and according to their economic label (same information represented in two different ways: cumulated vs. separated series).

son is that since 1975, regulations have imposed better thermal insulation for new homes heated with electricity than for other energies. In France, there are still 6.5 million dwellings (27 %) without any thermal insulation: 2.8 heated by gas, 1.9 by electricity, 1 million by "other" energies. The vast majority (5.3 million) are MFHs whose renovation is hampered by numerous obstacles (e.g. owner-occupant dilemma, co-ownership).

THE ECONOMIC INDICATOR: THE "NORMATIVE ENERGY BILL" IN EURO/(M^2.YEAR)

The "economic" indicator gives the theoretical energy bill (per m²) related to the regulatory end-uses of DPE that households would have to pay if they heat their dwelling in a normative way, i.e. according to the behavioural scenario of the DPE calculation. The definition of classes obviously has an influence on the distribution found: the vast majority of theoretical heating and DHW bills are in classes C to E, i.e. between 10 and 30 Euro/m².year[6]. Classes F and G represent 17 % of the stock, the MFHs and the oldest dwellings are over-represented in classes F and G.

Compared to the final energy indicator, the economic indicator introduces the unitary price of energy (Euro/kWh including VAT and subscription), which varies greatly according to energy (see Figure 1). This disparity can compensate for differences in energy performance between dwellings ("Ubat" and "final energy" indicators). Wood, which has a good "Ubat" indicator but high final energy consumption (very low normative efficiency of wood-burning appliances in the DPE) is the cheapest energy (per kWh), which allows it to be found in better economic labels. Gas and electricity, which have inverse rankings with the other indicators, have stock distributions close to those on the bill: the lower thermal performance of gas-heated dwelling is offset by a lower price than electricity. Fuel oil and "other" energy sources combine poor thermal performance and high-energy costs and are therefore downgraded.

THE "CLIMATE" INDICATOR OF THE FRENCH DPE: CO_2 EMISSIONS IN G CO_2/(M^2.YEAR)

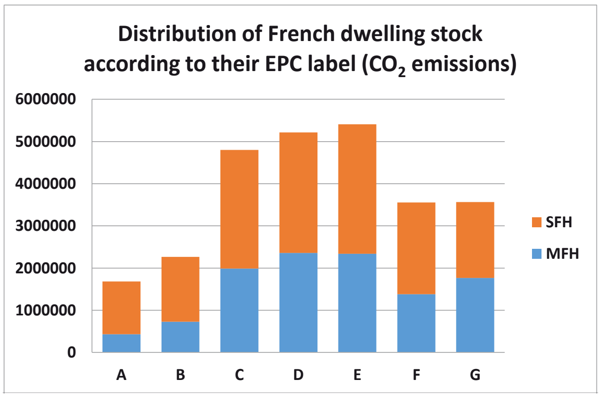
The distribution of the French housing stock according to the DPE climate label is more favourable than that of primary energy. Although the dominant class is (narrowly) the E label in both cases, classes A and B represent 15 % of the stock, making it the most optimistic French indicator. Nevertheless, 27 % of the dwellings have a climate label in F or G.

As with DPE in PE, MFHs are less efficient than SFHs and older dwellings are over-represented in classes F or G. On the other hand, the contrast between the energies is more pronounced and the hierarchy is reversed compared to the label in PE. 68 % of oil and LPG-heated dwellings and 51 % of "other" energy sources are in class F or G against 1 % and 2 % for wood and electricity, due to the French electricity mix.

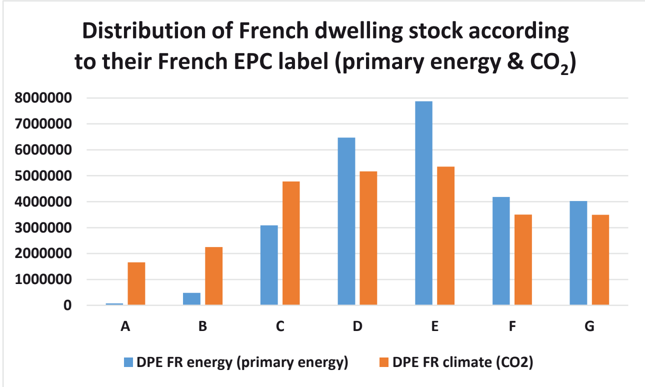
THE UK "ENERGY" INDICATOR: SAP ENERGY EFFICIENCY RATING

The two UK indicators are expressed on a scale from 1 to 100 and not in bands bounded by absolute values as elsewhere in Europe. This involves converting the energy bill and the theo-

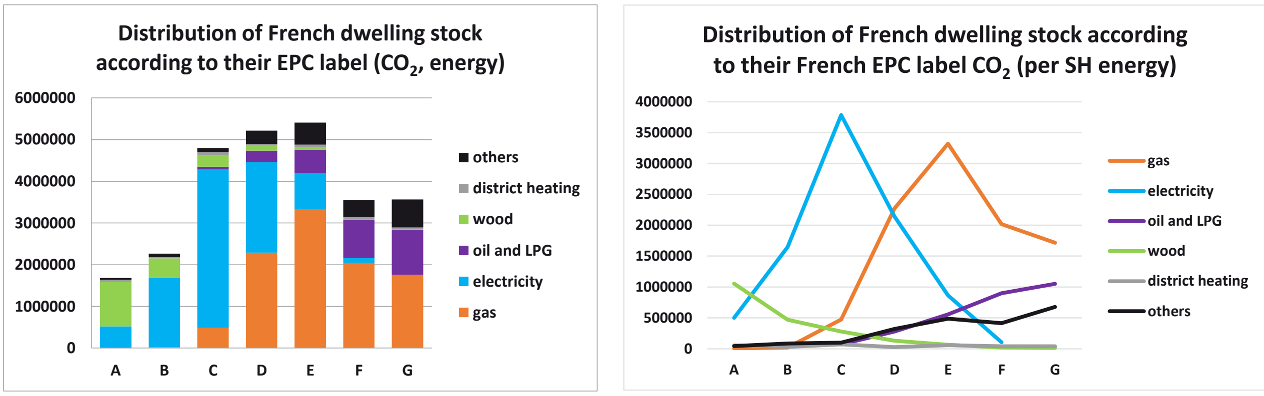
6. In 2013, according to CEREN, the average energy bill observed for heating and DHW was 9.5 Euro/m².



Figures 13. Number of French dwellings by French DPE climate (type of housing).



Figures 14. Actual comparison of French housing according to their DPE energy and climate.



Figures 15a and 15b. Number of French dwellings according to their DPE climate label (CO_2).

retical annual CO_2 emissions on a scale of 1–100. In the conversion, the surface area of the dwelling is taken into account and the calculation is made using several formulas[7] that take into account the characteristics of the UK housing stock. Applied directly to the French stock, these formulas lead to a negative value of the UK energy indicator for nearly 10 % of the stock, which is theoretically not possible in the UK method.

The explanation does not seem to come from the fact that, in the study, the calculation of theoretical final consumption is based on the French EPC underlying method (called "3CL") instead of SAP calculation because previous work has shown that the two methods have many similarities [Laurent et al. 2013], nevertheless additional work would be necessary to remove this uncertainty. The paper hypothesizes that this result is related to differences between the UK and French housing stock. The UK stock is much more homogeneous than the French one. It has only 17 % MFH [UK 2011] (48 % in France) and is overwhelmingly heated by gas [UK 2013] (85 %) while the number of French dwellings heated by electricity is almost equivalent to those heated by gas (36 % and 41 %). The price of energy and the efficiency of heating equipment are therefore very close for the vast majority of the UK stock, which is not the case in France. The homogeneity of the UK housing stock means that the UK energy efficiency indicator is as representative of the theoretical bill as it is of the primary and final energy consumption, or even the thermal insulation of the dwelling. In France, the differences in energy prices and efficiency of heating equipment between fossil fuels and electricity introduce significant heterogeneity in terms of energy bills. This hypothesis is reinforced by the fact that few dwellings with negative SAP values are heated with gas (15 %), compared to the shares from more expensive energies: fuel oil, "other" energy sources and electricity.

By adding dwellings with negative SAP values to those in class G, this class becomes the majority (30 %). In order to compare the UK energy performance indicator with the French indicator without changing the formulas for converting "blindly" the SAP calculation, it is chosen to rate dwellings with negative SAP in class G and to shift all other dwellings to the next best class. This offset distribution obtained has a more consistent look. The analysis will focus on this "offset SAP energy rating".

With the "offset SAP", 30 % of housing is in F or G (former class G), and unlike the French economic indicator, MFHs are slightly less ranked in F or G classes than SFHs. On the other hand, as with the other labels, dwellings built before 1975 are over-represented in F and G. Concerning heating energies, the distribution is significantly different from that of the French DPE Energy, which is explained since the two indicators are not of the same nature. Housing heated with fuel oil, gas and "other" energy sources loses one or two classes with the UK indicator, while electricity and wood gain one or two classes. It is more logical to compare the UK "energy" indicator with the

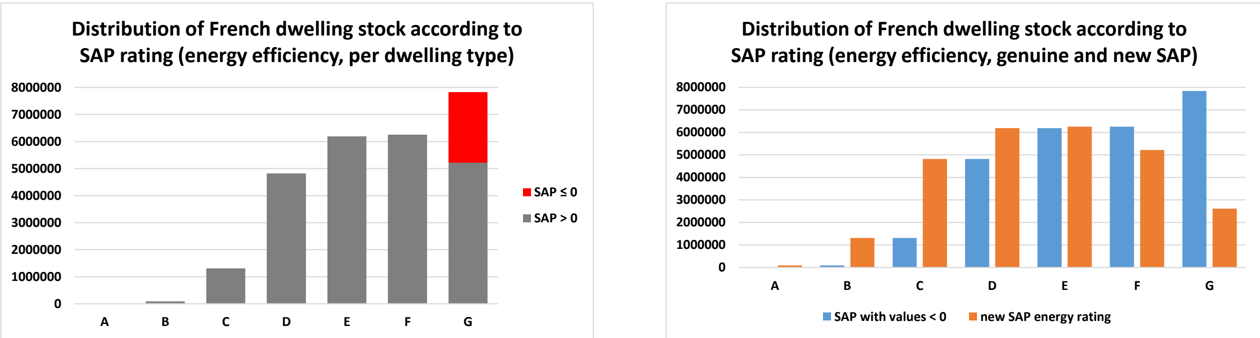
7. SAP 2012 edition, p. 37.

French economic indicator, which is also expressed in terms of energy bills. This time, the distributions are much closer, but with a shift from a label to a lower performance, especially for homes heated with fuel oil. The UK indicator includes more end-uses than the French economic indicator. However, the electricity consumption from lighting and ventilation is too small to explain all the difference.

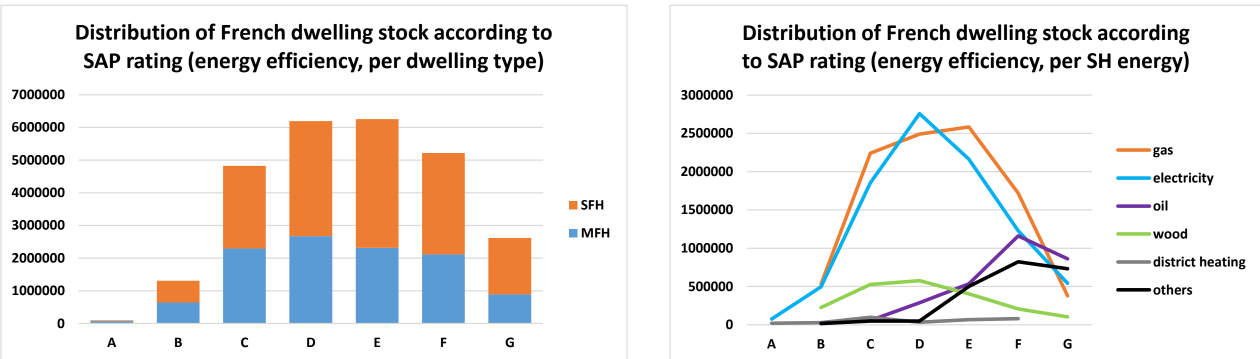
THE CO_2 UK INDICATOR: ENVIRONMENTAL IMPACT RATING (EI)

Unlike the UK energy efficiency indicator, there are very few negative values in the calculation of the Environmental Impact rating (EI), so the initial performance classes are kept. Since the majority of the energy consumption considered is for space heating, the reason probably comes from a smaller heterogeneity between the GHG emission factors for space heating (see Figure 2) of the different energies in France than between the different physical energy performance of housing and the different energy prices.

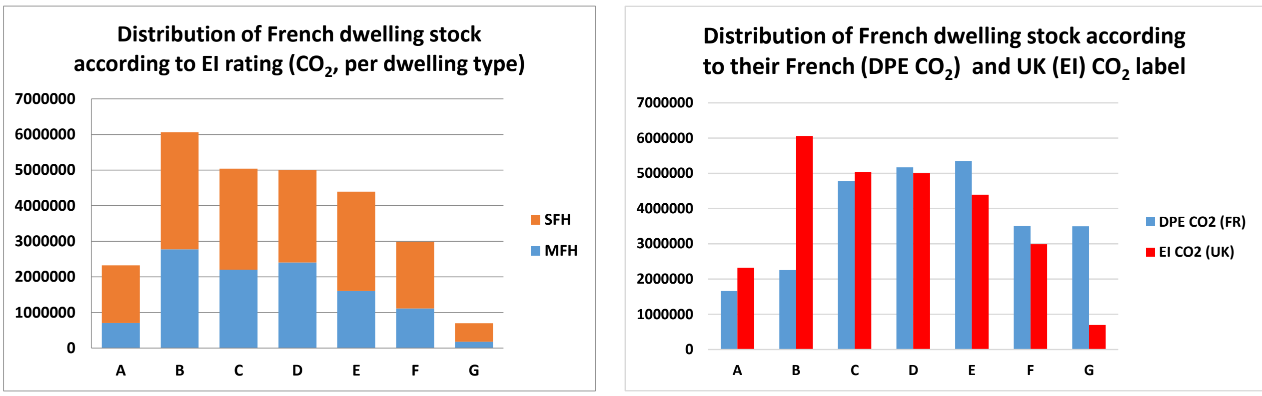
Generally speaking, the UK climate indicator performs better than the French climate indicator with a majority of the stock in class B and very few in class G. According to the UK indicator, apartments have a better climate performance than houses, unlike the French indicator. There is no immediate explanation for this difference.



Figures 16a and 16b. Number of French dwellings according to the UK EPC energy. (16a: the initial classification: the number of dwellings with a negative rating is in red, 16b: comparison of the EPC energy labels original version and new version for the paper "New SAP").



Figures 17a and 17b. Number of French dwellings by UK EPC energy label (offset SAP rating)(17a: by type of dwelling, 17b: by heating energy)(own calculation).



Figures 18a and 18b. Number of French dwellings according to the UK indicator EI (18a: type of housing, 18b: comparison of French and UK climate indicators).

For the criterion "main heating energy", the distribution with EI indicator is very close to the one with the French DPE CO_2 indicator with a shift label towards a better label.

The overall performance of the housing stock according to the different indicators: does a single indicator rule them all?

The performance of the French housing stock is measured according to the average class, the class with the highest frequency in terms of number of dwellings and the % of dwellings labelled in the two worst classes (F and G).

WHICH DWELLINGS ARE LABELLED IN F AND G ACCORDING TO THE CHOSEN INDICATOR?

As French dwellings labelled in F or G will have to be renovated by 2025 the latest (LTE 2015), it is interesting to detail the nature of the dwellings ranked in these classes according to the different indicators. There is almost a factor of three on the number of housing units ranked F or G, but there are also significant differences on the nature of the units labelled F or G.

MFHs are more often ranked in F or G than SFHs with French indicators. UK indicators preferentially select SFHs. The heating energies that are most often selected in F or G are fuel oil and "other" energy sources because they combine poor performance (consumption, climate, price) and to a lesser extent, gas.

ARE THERE ANY DWELLINGS THAT HAVE THE WORST LABEL FOR ALL INDICATORS?

The analysis is done only with the French indicators. Despite the diversity of nature of the indicators, more than 5 % of the French housing stock is rated in F or G for all indicators. These dwellings are therefore to be renovated regardless of the perspective chosen. Not surprisingly, the vast majority (95 %) of the dwellings concerned were built before 1975, but unlike the results obtained indicator-by-indicator, it is mainly SFH (62 %) that have the worst labels. Their heating energies are fuel oil and "other" energy sources, of which the stock were over-represented in classes F or G, but especially gas, which dominates with 44 % of the stock.

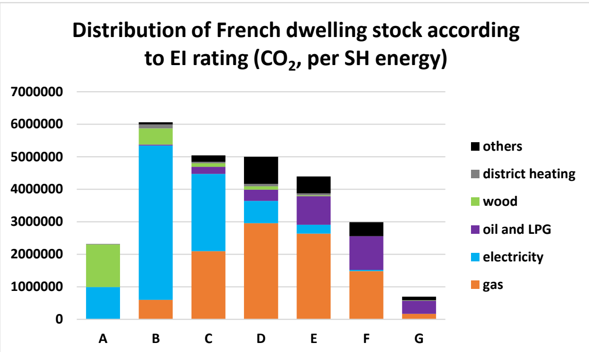


Figure 19. Number of French dwellings by UK EPC climate label (per heating energy).

Conclusions and discussion

The energy performance of the French housing stock varies greatly depending on the indicator chosen to characterise it: housing with an F or G rating for all French indicators represents 5 % of the stock. This is explained by the very different nature of the performance indicators studied (energy consumption at different stages, CO_2 emissions, energy bill). The dwellings ranked in F and G are also very different from one indicator to another. The heterogeneity of the French housing

Table 3. Performance of French housing stock according to the seven indicators.

	French EPC (DPE)					UK EPC	
	Primary Energy (PE)	Climate (CO2)	Final Energy (FE)	Useful Energy (Ubat)	Economic label (€)	Energy (new SAP 1-100)	Climate (EI, 1-100)
average class	E	E	D	F	D	D	D
majority classe	E	E	D	G	C	E	B
% in majority class	30%	20%	29%	24%	24%	24%	23%
% in class F and G	31%	27%	16%	39%	17%	30%	14%

Table 4. Nature of dwellings classified in F or G according to the indicator.

Type of indicator		Type of dwellings representing the highest shares in F and G classes
France	PE	MFHs heated with electricity, fuel oil and wood
	Climate (CO2)	MFHs heated with fuel oil, "other" energy sources and gas
	FE	dwellings heated with fuel oil, wood and "other" energy sources
	Thermal insulation (Ubat)	MFHs heated by district heating network, "other" energy sources and gas
	Economic (€)	MFHs heated by "other" energy sources, fuel oil and electricity.
UK	"Energy" (SAP)	SFHs heated with "other" energy sources, fuel oil and gas
	Environmental Impact (EI, CO2)	dwellings heated with fuel oil, "other" energy sources and gas

stock does not seem to compensate for the variety of nature of the indicators studied, but on the contrary, it adds diversity.

Significant differences also persist when comparing the performance assessed by the French and UK indicators. The French "DPE primary energy" and the UK "EPC energy" seem to give similar overall results although they are of different natures (primary energy for the French DPE and energy bill for the UK EPC). This apparent similarity is in fact the result of individual differences that offset each other at the national level because the two indicators do not give the same label to the same dwelling. In practice, the UK EPC energy is an economic indicator and should therefore be compared to a French indicator of the same nature. The comparison shows that the UK indicator is more severe than the French indicator. The nature of the indicator is not in question, which is confirmed by the fact that 95 % of the dwellings selected in F or G by the French indicator are also selected by the UK indicator. It is the definition of the limits of the energy performance classes – which is not the same between France and UK – that seems to be the main explanation. For the "energy" efficiency indicators, the differences in the evaluation of the French and UK indicators therefore come both from the difference in the nature of the two indicators and from the differences in the definition of performance classes.

The comparison of French and UK climate indicators (CO_2) shows that the UK indicator is this time more optimistic than the French indicator. Here again, 100 % of the dwellings selected in F or G by the UK indicator are also selected by the French indicator. For the climate indicator, the differences in rating come only from the definition of performance classes, which is not the same between France and the United Kingdom, the French classes being more severe this time.

In the end, apart from label shifts, there are few differences in the distribution of buildings per label seen from the French and UK indicators, provided that indicators of the same type are compared.

However, the use of UK indicators to evaluate the performance of French housing has its limitations. Beyond the difference in nature for "energy" indicators, the original formalism of the UK indicators does not seem to be adapted to the French context. The UK indicators are standardized and the standardization process is done using formulas and coefficients calibrated for the UK stock. The large differences between the French and UK housing stock probably explain why 10 % of the French housing stock obtains a negative rating with the UK EPC energy, which is not provided for in the UK standard. The one-class offset, which was necessary in order to compare the results of the French and UK indicators, necessarily has an impact on the results, which moderates the conclusions. To go further, the analysis should be differentiated between houses and apartments in view of their strong differences in performance and the fact that the UK indicators have been based on the UK housing stock, which is overwhelmingly composed of houses. Finally, and although that this is probably not the cause of the differences between the UK and French indicators, a study using the normative energy consumption of dwellings calculated from the UK SAP thermal model instead of the normative consumption calculated with the 3-CL model of the French DPE would remove the uncertainty on the impact of the thermal model.

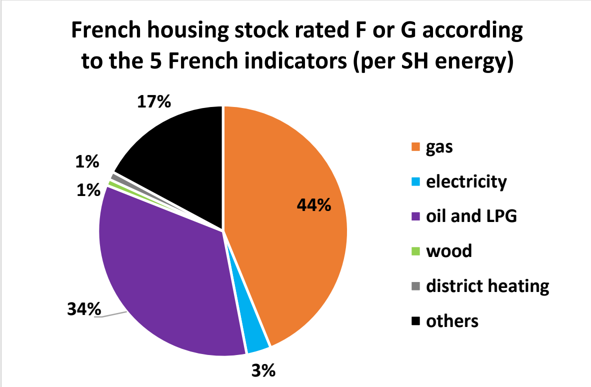


Figure 20. Housing classified in F or G for all French indicators according to heating energy.

However, whether in France or the UK, using a single indicator seems illusory. There seems to be a need to distinguish two situations:

- Providing information to owners (or tenants) about the energy performance of the dwelling, and what actions can be done to improve it. This is the initial objective of the European EPC.
- Analysing the building stock and targeting the dwellings that should be renovated in priority. The chosen indicator is a support to policy design.

A household's interests in terms of housing and those from energy policies are not necessarily the same. This paper is focused on the second point, but the objectives of housing renovation campaigns may be different, and therefore not define the same priority actions (reduction of GHG emissions, energy bills, energy imports, etc.). A different indicator will therefore have to be used depending on the objective. When it comes to defining concrete renovation programmes and the associated technical measures, indicators with a broad scope are not very effective. Indicators corresponding to a smaller perimeter (or energy stage) should be used. The Ubat indicator makes it possible to identify dwellings whose buildings are to be insulated, while more global indicators do not necessarily identify them (only 48 % of dwellings labelled as F or G by the Ubat indicator are also labelled as such with the French DPE indicator in primary energy). A low-performance building can be compensated by high-performance equipment (low energy consumption) or low-cost energy (low energy bill) or low CO_2 emissions (low-carbon energy). The same reasoning applies to housing with poor economic performance.

It is interesting to cross-reference the indicators: for example, a dwelling with a good Ubat level but a poor final energy indicator is a sign of a low-performance energy equipment directs the renovation of the dwelling towards the replacement of heating or domestic hot water equipment.

Currently in France, the DPE in primary energy is the only energy performance indicator actually used to inform households about the level of performance of their housing, evaluate the performance of the dwelling stock and guide public policies. Although households have two pieces of information at their disposal (energy performance and climate), only the DPE indicator in primary energy can provide subsidies or loans at subsidised rates. Despite the fact that France has ambitious targets for reducing GHG emissions (carbon neutrality by 2050), the climate performance indicator (CO_2) is never used to obtain subsidies, subsidised loans or select housing for renovation.

It is also the DPE in primary energy that selects the housing that will be subject to an energy renovation obligation from 2025.This work shows that this indicator is not the most appropriate one. It is preferable to cross-reference the Ubat and final energy indicators to determine whether to insulate the envelope, replace the heating equipment or both. From a general point of view, it is profitable to use different indicators depending on the energy policy objective being pursued. This does not require a new DPE calculation chain since all the indicators proposed in this paper are intermediate results of the calculation of the current French DPE. Even the economic indicator is already present: an informative annex to the DPE provided to the occupant of the dwelling gives an assessment of conventional energy bills (although energy prices would need to be updated …). Enriching the current DPE on the basis of the proposals made in this paper without changing the current calculation chain is a simple operation that could be carried out during the revision of the French DPE scheduled for 2019.

This plurality of indicators would make it possible to better define the programmes designed to achieve the various energy policy objectives. For household information (the initial mission of the EPC), this would make it possible to establish more relevant individualised renovation recommendations. The question arises as to whether it is useful to bring all these other indicators to the attention of the household whose dwelling is the subject of an EPC. Do the owners and tenants need a set of various indicators or do they need one or two simple indicators they can easily understand, complemented with reliable recommendations for actions, and what are they? This study did not address the question of the relevance of the current EPC and its indicators from the perspective of households, but rather its relevance as a tool to achieve energy policy objectives. To investigate this question requires another study.

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DISCLAIMER