The influence of uncertainties related to the inputs of the French EPC's calculation method -an analysis for individual houses

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Abstract
The French EPC (Energy Performance Certificate) was implemented in 2006 to be mandatory for selling or renting a dwelling. From the beginning, the EPC's robustness was questioned. Field tests showed that, for the same building, two different energy labels could be obtained from auditors. Thus in 2012 the EPC was revised to make it more reliable by, among others, doubling the number of inputs in the calculation method. Unfortunately, recent investigations show that the problems persist whereas a law plans to make EPC enforceable against third persons in 2021. In this way, the French government has announced a new rework of the EPC for 2019. In this context we study the part in the dispersion of EPC's results due to the calculation method.

In 2011 a first study consisted of an uncertainty propagation (Monte-Carlo method) and a sensitivity analysis in the initial version of the calculation method (2006 method) on the case of a single-family house. Using the same case and the same methodology (and also Sobol method), we are able to compare the differences between the initial and revised calculation methods. The revised version is not more accurate and some main sources of dispersion in the EPC's results are identified:

- in all input modes, estimated energy consumption has increased while the EPC is known to overestimate actual consumption,
- we observed a doubling of consumption's dispersion,
- significant differences in results exist between the input modes ("precise input" vs. "default value" with threshold effects in the value tables),
- a large part of discrepancy depends on the uncertainties on transmission coefficients of the thermal insulation and on the surface area.

In conclusion, in association with the question of the qualification of diagnosticians, the calculation method must be deeply reworked so that the EPC becomes the main tool of the building stock refurbishment.

Introduction
The Energy Performance certificate (EPC), is a tool for establishing the Energy and Climate labels of a dwelling. Its implementation is the result of the energy efficiency of buildings directive (Directive 2002/91/EC – EPBD) (JOCE 2002). In France, the EPC was implemented through a law in 2006 (JORF 2006), and has become mandatory in the case of sale, rental or construction of a dwelling. The French EPC provides an overview of the energy performance of a dwelling by estimating its primary energy consumption and greenhouse gas emission.

Unfortunately, the EPC'06 was quickly criticized for its unreliability and differences in results for the same buildings depending both on the different usable methods and diagnostician assessments (Ebran and Matricon-Delbé 2008, Raynaud & Stabat 2011). It should be noted that similar results have been observed in other European countries (Tronchin and Fabbri 2012, Mangold et al. 2015).

In order to improve its reliability, the French EPC was updated in 2012 (JORF 2012). One consequence of the 2012 revision is the twofold increase of the input data in order to make a more accurate calculation.

However, this work does not seem to have really solved the EPC reliability problems. Differences of nearly 3 energy classes for the diagnosis of the same dwelling were observed, often highlighting the lack of rigour and professionalism of some diagnosticians (Chesnais and Bourcier 2017). Faced with this persistent problem of unreliability, the ministry responsible for the EPC has decided to revise it again (MTES 2018). The objective is for the EPC to be technically reliable and enforceable by 2019.

In this context, this study has two objectives: to update with the EPC'12 an initial 2011 study, consisting of an uncertainty propagation and a sensitivity analysis in the first version of the calculation method (EPC'06) on the case of a single-family house (Raynaud and Stabat 2011), and then to extend it to other cases to make the conclusions more general.

Methodology

In this part, we present in first the French EPC's calculation method, then the uncertainty methodology used and finally, the dwellings on which we based our study.

EPC CALCULATION METHOD

EPC is mainly used for estimating the area ratio of the annual energy consumption of the dwelling, expressed in kWh/(m².year) of primary energy (pe), at the base of the Energy label (*e.g.* only the Energy label is mandatory on real estate advertisements). In the calculation method, the annual energy consumption is the sum of the annual energy consumptions for heating, cooling and domestic hot water (DHW). These consumptions are calculated on the basis of use standard scenarios: set heating temperature of 19 °C reduced to 16 °C between 10:00 pm and 6:00 am, *etc*.

The estimation of the heating energy consumption is based on three main steps: a calculation of the thermal losses by the opaque building envelope, the windows, the thermal bridges and the air change, then a calculation of the heating demand integrating an intermittency factor, the weather (30-year averages), the internal heat gains and the free external heat gains limited by the near and far masks, and finally a calculation of the energy consumption incorporating the emission, distribution, regulation and generation efficiencies of the heating installation. The estimation of the energy consumption for DHW production is done from correlations according to the living area and the climatic zone to determine the DHW demand and the distribution, generation and storage efficiencies of the installation. The estimation of the cooling energy consumption is based on correlations according to the living area, the percentage of air-conditioned area and the climatic zone.

The method offers six possible modes for entering the thermal characteristics of the building envelope components, parameters necessary for calculating the thermal losses:

- Entry of the heat transfer coefficient (U) of the opaque component or the window. We will call this input mode the "U of component known" mode,
- Entry of the thermal resistance (R) of the insulation in the opaque component, the U of the supporting part of the opaque component and the U of the windows being entered by default according to their materials and characteristics (the windows are treated in the same way for all other modes). We will name it the "R of insulation known" mode,
- Entry of the insulation thickness (T), the insulation thermal conductivity (λ) being fixed by default and the U of the supporting part determined as in the previous mode. We will call it the "T of insulation known" mode,
- Entry of the insulation year, the U of the opaque component is then selected among default values associated with different insulation periods. We will name it "Year of insulation known",
- Entry of an insulation presence in the component but whose year is unknown, then the U of the opaque component is determined among default values associated with different construction periods. We will call it the "Year of insulation unknown" mode.
- If the component is totally unknown, which we will call the "Component unknown" mode, the U of the opaque component is chosen from default values associated with different construction periods.

It should be noted that regardless of the input mode chosen, the area of the building components (area of walls, area of windows, *etc.*) must be known. The EPC's method allows for the same dwelling to define a building component (e.g. the walls) with one input mode (*e.g.* "U of component know" mode) and another component (e.g. the floor) with another input mode (*e.g.* "T of insulation known") however in our study, to facilitate the analysis of the results, we did not mix the input modes and thus when we refer to a mode, it has been applied to all building components of the dwelling studied.

Depending on the input mode, we identified between 92 and 111 inputs[1] (*i.e.* parameters whose definition does not depend on any other) necessary to the calculation.

UNCERTAINTY METHODOLOGY

Monte-Carlo method

The Monte-Carlo method consists in generating multiple input sets by independently and randomly varying all input values around their expectation value and according to their probability distribution (mathematical expression of their uncertainty). After a sufficient number of input sets have been generated and propagated in the calculation method, all possible outputs of the model have been statistically obtained, and we can then measure the resulting uncertainty on the output.

To properly apply this method, we first had to estimate the uncertainties related to the inputs of the calculation method. All inputs were separated into two groups: the certain parameters (*i.e.* without uncertainty) and the uncertain ones (*i.e.* with uncertainty). The certain parameters are taken as fixed in all the

1. 92, 107 and 108 inputs for respectively the "U component known", "Component unknown", "Insulation year unknown" modes and 111 inputs for the 3 other modes.

Table 1. Main characteristics of the EPC output distributions obtained for the different input modes in the 2011 study (Raynaud and Stabat 2011) and this study (Monte-Carlo method).

Input mode – Year of the concerned study	Minimum of the distribution (kWhpe/(m².year)	Maximum of the distribution (kWhpe/(m².year)	Average of the distribution (kWhpe/(m².year)	Standard deviation of the distribution (kWhpe/(m².year)
U of component known – 2011	211	273	241.5	6.9
U of component known – 2019	200	310	250.3	15.7
R of insulation known – 2011	200	249	222.9	5.7
R of insulation known – 2019	207	310	253.9	15.3
T of insulation known – 2011	200	234	216.4	4.4
T of insulation known – 2019	200	300	246.6	14.4
Year of insulation known – 2011	226	264	245.2	4.8
Year of insulation known – 2019	200	345	260.3	21.1
Year of insulation unknown – 2011	–	–	–	–
Year of insulation unknown – 2019	230	345	280.3	16.4
Component unknown – 2011	208	272	249.1	12.6
Component unknown – 2019	215	345	284.2	20.6

generated input sets. They include housing characteristics with no or negligible uncertainty (such as the department, the number of floors, type of heating systems, *etc.*). The other inputs are not known with certainty by the diagnostician (thermo-physical parameters, *etc.*), the measured values (areas, thicknesses, *etc.*) or not visible (presence of a rare gas strip in the double glazing, *etc.*). We have assigned, from the literature (Mastrucci and al. 2017, Zhang and al. 2016, Raynaud and Stabat 2011) to each of these inputs an uncertainty. In a practical way, we randomly generated, using a Python code, 10^6 input sets for each of the 6 possible input modes, in order to obtain a compromise between precision and speed of calculation.

Sobol method

The Sobol method is a sensitivity analysis and consists in studying and quantifying the impact of each input and its associated uncertainty on the dispersion of output values in order to determine the most influential inputs. More specifically, this analysis method makes it possible to estimate, via the calculation of the Sobol indexes, the part of the total variance of the output due to each input and its associated uncertainty (expressed in %).

THE DWELLING OF THE 2011 STUDY

The first case study is a two-storey single-family house (SFH) from 1980 with a living area of 85 m² located at an altitude of 800 m (this choice of altitude allows us to take into account the influence of this parameter, present only around 800 m[2]). The walls are made of solid concrete blocks (dimension 20 cm*20 cm*40 cm) with an internal insulation of 4 cm (thermal conductivity[λ] of 0.043 W/(m.K)). The floor, on crawl space, is composed of a 15 cm thick concrete slab and 4 cm of insulation (λ of 0.043 W/(m.K)). The ceiling, on attic space, is a ceiling under wooden joists with 8 cm of insulation (λ of 0.047 W/(m.K)). The windows are with double glazing (4/10/4). A natural gas boiler, dating from 2005, provides space heating as well as instantaneous DHW production. Ventilation is achieved by a self-adjusting 1981 controlled mechanical ventilation (CMV). Finally, we note the presence of distant masks: dwellings of the same type are present on the other side of the street, in the North at 25 m, as well as in the South, East and West at 10 m.

DWELLINGS OF THE FRENCH HOUSES STOCK

We subsequently extended this study to a sample of SFH in order to better represent the diversity of situations in the French housing stock. We studied a same dwelling on which we varied the type of energy for space heating (electricity or gas), the construction year (1968, 1978 and 1988) and the level of insulation (retrofitted or not retrofitted). In order to be as representative as possible of the main characteristics in the French houses stock, the studied dwelling is one storey house with a living area of 99.84 m², considered to be in north of France at an altitude of 100 m. Thereafter, the set of insulation and space heating system depends on the year of construction or retrofit of the dwelling.

Results

IMPACT OF THE 2012 REVISION – UPDATE OF THE 2011 STUDY

A first comparison between the results of the 2011 study and those of this study shows that the calculated average consumptions have increased by about 20 kWhpe/(m².an) on average (Table 1). It therefore seems that the addition of inputs (taking into account masks, more detailed consideration of systems and their efficiency, *etc.*) in the EPC'12 compared to the EPC'06 has led to higher consumption, whereas the old method was already known to overestimate calculated consumption compared to actual consumption (Laurent and al. 2013).

In view of the results obtained, we also see that the new method does not seem more reliable than the old one in terms of obtaining less dispersed results. Indeed, for our case study, while consumptions varied over all the input modes for the EPC'06 over an interval of 72 kWhpe/(m².an) (between 200 and 272 kWhpe/(m².an)), with the EPC'12, consumptions vary over an interval of 145 kWhpe/(m².an) (between 200 and 345 kWhpe/(m².an)), which represents a doubling of consumptions dispersion. Thus, in terms of Energy labels, 3 bands could

2. Above 800 m, regardless of the altitude value, a same major climatic correction is applied by the method. Below 800 m, no correction is applied.

Table 2. The most influential inputs on the EPC'12 output for the different input modes (Sobol method).

Input	Uncertainty (distribution, confidence interval at 99 %)	U of component known – Sobol indice (importance rank)	R of insulation known – Sobol indice (importance rank)	T of insulation known – Sobol indice (importance rank)	Year of insulation known – Sobol indice (importance rank)	Year of insulation unknown – Sobol indice (importance rank)	Component unknown – Sobol indice (importance rank)
Living area	Normal, ±15.5 %	46 % (1)	50 % (1)	51.6 % (1)	27.9 % (2)	57.1 % (1)	37.3 % (2)
Altitude	Normal, ±20 %	18.7 % (2)	20.1 % (2)	21.8 % (2)	5.1 % (3)	21.9 % (2)	5.7 % (4)
U of walls	Normal, ±21.1 %	15.9 % (3)	–	–	–	–	–
R of insulation in walls	Normal, ±21.1 %	–	9.7 % (3)	–	–	–	–
Area of walls	Normal, ±15.5 %	7.3 % (4)	8.4 % (4)	9.7 % (3)	4.5 % (4)	11.8 % (3)	6.8 % (3)
T of insulation in walls	Normal, ±15 %	–	–	4.3 % (4)	–	–	–
Height of far masks	Normal, ±38 %	3.4 % (5)	3.6 % (5)	4.1 % (5)	1.9 % (5)	3.4 % (4)	2 % (5)
Distance of far masks	Normal, ±38 %	3 % (6)	3.1 % (6)	3.6 % (6)	1.6 % (6)	2.9 % (5)	1.8 % (7)
Area of floor	Normal, ±15 %	2.8 % (7)	2.6 % (7)	3 % (7)	1.4 % (7)	2.7 % (6)	1.9 % (6)
U of floor	Normal, ±17.2 %	1 % (8)	–	–	–	–	–
T of insulation in floor	Normal, ±20 %	–	–	0.7 % (8)	–	–	–
Length of thermal bridges	Normal, ±15 %	0.5 % (10)	0.5 % (8)	0.6 % (9)	0.3 % (8)	0.4 % (7)	0.3 % (8)
Year of construction/ insulation	15 % probability for being in period before and idem for period after	0.2 % (13)	0.2 % (11)	0.2 % (10)	53.1 % (1)	0.3 % (8)	42.9 % (1)

be diagnosed (D, E and F) with the EPC'12 whereas 2 bands could be diagnosed (D and E) with the EPC'06.

In a more detailed observation, 2 distribution groups appear in the results of this study:

- One group associated with the precise input modes (U of component, R of insulation, T of insulation known modes), for which the calculated average consumptions are close to 250 kWhpe/(m².an) and the standard deviation is close to 15 kWhpe/(m².an),
- One group linked with the unprecise input modes (year of insulation known, unknown and component unknown), for which the calculated average consumptions (between 260 and 284 kWhpe/(m².an)) and the standard deviations (between 16.4 and 21.1 kWhpe/(m².an)) are higher than in the other group.

Thus, the different input modes offered by the method are themselves sources of dispersions in the results.

Table 2 brings together, for each of the 6 input modes, the most sensitive data inputs on the EPC'12 output. First, we observe that among the most influential data inputs are building and environmental inputs and not system inputs. More precisely, regardless of the input mode, the living area and the altitude are found very influential inputs. However, with regard to altitude, it should be noted that in our case study, its value is just at a significant change threshold (at 800 m) which certainly gives it an overestimated importance. Then for the inputs modes associated with the thermo-physical parameters known (U of component, R of insulation, T of insulation known), these parameters (and particularly those associated with walls) are precisely among the most influential data inputs. Likewise, for the input modes linked with the year of construction or insulation (year of insulation known, unknown and component unknown), the year of construction or insulation is an important influential input. Finally, whatever the input mode, the height and distance of the far masks, new parameters that appeared in the EPC'12 method, are found to have a certain impact on the result (importance ranks between 4 and 7).

In addition, most of the influential data inputs highlighted in the 2011 study for the "U of component known" mode[3], the only mode treated in 2011, still appear to be influential in the new method (EPC'12). Thus it seems that changes between the two methods (EPC'06 and EPC'12) have not neutralized nor reduced the influence of the most influential inputs on the dispersion of results.

3. In order of importance: U of walls, living area, altitude, U of floor, U of roof, area of walls, U of windows.

GENERALISATION OF THE STUDY AND IMPACT OF REFURBISHMENT ON EPC LABELLING

We studied dwellings using different energy inputs (electricity or gas) for space heating, different vintage (1968, 1978 and 1988) and different levels of insulation (retrofitted or not) for the old ones (Table 3, 4) in order to extend the scope of our analysis.

The results confirm those presented above whatever the building vintage. Due to page number constraints, we will not present details here. We refined in these results the group associated with the precise inputs (U of component, R of insulation, T of insulation known), whose average consumption calculated for each mode is very close, and whose standard deviation is relatively small. In addition, the other three input modes associated with unprecise inputs (year of insulation known, unknown or component unknown) have also a much larger standard deviation and an average consumption that varies widely and randomly compared to the other modes.

The spread of values for electric space heated dwellings appears to be higher than for gas space heated ones. Indeed, since the average consumption is higher for buildings running on electricity (due to the primary energy factor: 2.58 for electricity and 1 for gas), the dispersion of consumption values is also higher. With identical dispersion in final energy, in primary energy the dispersion for electricity would be 2.58 times higher than for gas. Thus, we observe (Table 3) that the standard deviations for the most accurate input modes for a gas dwelling are on average 12 kWhpe/(m².year), while they are twice as high for an electric dwelling.

The EPC Energy label for the same dwelling can vary, according to our results, and according to the input mode used, up to 4 different bands (Table 4). In the other cases, there are at least 2 bands with significant probabilities for the same dwelling.

We then focus on the impact of renovations and EPC labelling changes. We observe strong dispersions for retrofitted houses with the "Component unknown" mode leading to residual G bands (Table 3 and Table 4). In effect, when the building components are unknown, the method simply takes into account the year of construction of the building (for 1698, uses default values correspond to no insulated components), which can be a source of aberrations when the dwelling has been retrofitted. In real life, this configuration is more or less likely to exist depending on the age of the renovation.

At last, we can note that the majority of the most influential inputs remain so in the dwellings studied (Figure 1).

Conclusion and policy implications

The analysis of uncertainties related to the French EPC confirms previous studies. In addition, the 2012 revision of the initial 2006 method may have worsened some results. The main results and messages from this study are the following:

- A comparison of EPC'06 and EPC'12 on the same dwelling shows that calculated energy consumption has increased by about 20 kWhpe/(m².year) on average,

Table 3. Average and standard deviation of primary energy consumption (kWhpe/m²) by vintage and space heating energy from the different input modes (Monte-Carlo method).

Input	U of component known	R of insulation known	T of insulation known	Year of insulation known	Year of insulation unknown	Component unknown
1968 – gas	414.0, 24.0	non-insulated house				442.0, 87.5
1968 – electricity	436.4, 27.0	426.1, 25.3	430.6, 25.3	451.2, 26.2	437.7, 25.4	825.0, 163.2
1968 – gas – retrofitted	189.2, 11.0	201.5, 11.1	204.6, 11.1	205.0, 13.2	246.6, 13.3	452.3, 86.5
1968 – electricity – retrofitted	337.5, 21.6	376.8, 21.0	382.2, 21.1	382.5, 24.4	458.7, 25.0	842.1, 161.5
1978 – gas	223.5, 14.0	216.6, 13.1	220.4, 13.1	207.4, 19.0	224.2, 13.1	225.9, 19.1
1978 – electricity	444.0 25.0	431.3, 18.8	438.8, 23.7	435.7, 29.5	470.0, 25.0	435.7, 29.5
1988 – gas	203.2, 11.5	199.5, 10.9	201.3, 10.9	198.8, 16.8	232.3, 22.0	213.8, 20.9
1988 – electricity	380.4, 21.8	369.6, 20.6	379.3, 21.0	384.5, 30.7	445.6, 41.0	384.5, 30.7

Table 4. Distribution of SFH energy bands by vintage and space heating energy from the different input modes (Monte-Carlo method).

Dwelling vintage	Space heating energy	C band	D band	E band	F band	G band
1968	Gas	–	2 %	6 %	**52 %**	40 %
	Electricity	–	–	<1 %	**59 %**	40 %
1968 – retrofitted	Gas		**67 %**	18 %	<1 %	13 %
	Electricity			<1 %	**72 %**	26 %
1978	Gas	<1 %	**73 %**	26 %	–	–
	Electricity	–	–-	<1 %	**59 %**	40 %
1988	Gas	<1 %	**84 %**	15 %	–	–
	Electricity	–	–	<2 %	**89 %**	10 %

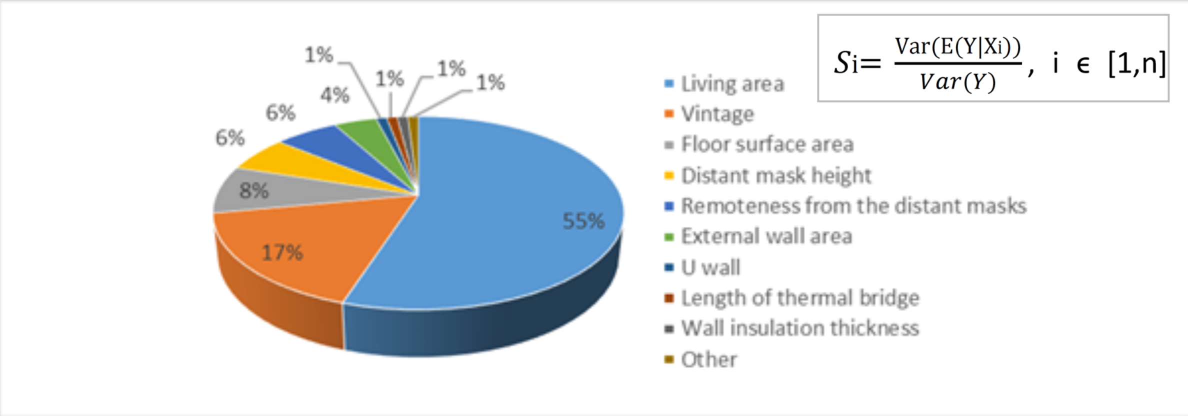

Figure 1. The most influential inputs on the EPC'12 output (1968/1978/1988 SFH cumulated) (Sobol method). Sobol index (S_i): contribution of the results (Y) variance due to each input (X_i) uncertainty (expressed in %).

- with an increase in dispersion: consumption varied for EPC'06 within an interval of 72 kWhpe/(m².year), whereas with the EPC'12, the interval is 145 kWhpe/(m².year).
- Significant differences in results between the input modes are observable (precise input vs. "default value" with a threshold effect in the reference value table).
- Different uncertainties between gas and electricity to the detriment of the latter (higher uncertainty) are noticed.
- The "Component unknown" input mode does not allow retrofitted houses to be valued.

We can suggest ways to improve the EPC methodology in the limits of our study results. First, to the extent that increasing the number of inputs increases the uncertainty about the output, reducing the number of inputs to the most influential ones can be effective. At the same time, care must be taken to ensure that these remaining influential inputs present less uncertainty. For example, to avoid excessive jumps in values when they are taken from reference tables (*e.g.* U of the building component), a linearization of these parameters by formulas is advisable. Or at least, setting up tables with the same intervals and value jumps between input modes is important. This avoids differences between input modes due only to a different U value. Thus, in the "Year of insulation unknown" mode, the number of intervals should be increased to avoid the significant jump in value in 1988, and for the 2 entry modes related to the year of insulation known or unknown, it is appropriate to increase the number of columns to differentiate the different types of energy in dwellings. In the same concern to standardize between the different modes, to avoid extreme value in the case of a "Component unknown" mode, but the house is renovated, it would be necessary to differentiate between dwellings that have been renovated or not since their construction. Then, the altitude is also a concern in some case when the housing is close to a threshold value. Indeed, it is very influential around 800 m or more (second most influential inputs), and in other cases (lower altitude) it does not count towards the calculation of consumption. Thus, linearizing its influence on meteorology (more than a change of class), could be effective.

Finally, the calculation of consumption is obviously always fraught with uncertainties, even if they are minimized. Therefore, giving a single consumption value of a dwelling per square metre for EPC will always be prone to error. Framing consumption by two values (to give a range of values) therefore seems to be a solution. The resulting interval could then overlap two energy labels, and thus mark the uncertainty about the assessed efficiency of the dwelling.

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