An energy efficiency program analysis to understand the gaps between *ex-ante* and *ex-post* evaluations

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Abstract

There is a gap between whole house energy consumptions calculated by engineering models and observed consumptions as reviewed in literature. This is especially true after retrofitting actions but the reasons are not well understood. Is it due to assumptions made in models, to uncertainties on input data, notably concerning behaviour, or to a no controllable random error?

In order to tackle this problem, a statistical modeling approach has been developed to study deviations before and after refurbishment on a panel of refurbished dwellings in France of which annual consumptions "before" and "after" are known.

In the first step, a statistical model of deviations between consumptions calculated by an engineering model and observed ones **before retrofitting** is established. Explanatory variables are building typology, energy systems data and household behaviour data. This model allows to identify the main sources of deviations before refurbishment and to quantify their effects.

In the second step, a similar statistical model of the deviations between simulated and observed consumptions **after retrofitting** shows that the variables linked with the refurbishment (i.e. type of measure…) do not explain errors, excepting set point temperature change. But the observed effect (the error decreases with an increase of set point temperature after retrofitting) does not go to the logically expected direction. A modeling flaw seems be partly the cause for this result. Uncertainties of this work and prospects are also discussed.

Introduction

The potential of energy savings in housing sector in the EU has been evaluated in recent years and ranked as an accessible way of reducing energy consumption. Unfortunately, these evaluations are mainly based on *ex-ante* assessment (e.g. Lechtenböhmer & Schüring 2011) and few studies in EU aimed at assessing *ex-post* energy savings at a large scale.

However, it is well-known that expected energy savings or consumptions aren't identical to measured ones (Hens 2010, Branco et al. 2004, Hong et al. 2006). After implementing energy efficiency measures, observed consumption is generally higher than expected due to a number of effects (e.g. rebound effects (Hens, Parijs & Deurinck 2010)).

In France, simple assessments of space heating energy savings are mostly based on the same modeling framework, derived from the 1988 French thermal regulation for new buildings, for example in the Energy Performance Certificate (EPC) (Ministère 2006), or for some prospective studies on residential consumptions (Thirion 2010).

Nevertheless, empirical evidence suggests significant differences between observed consumptions and those calculated with models like EPC (Allibe, Laurent & Osso 2010). The large difference observed at the building level has of course an impact on the estimated energy savings. This deviation could be explained by various points in the calculation methodology related to technical and behavioural considerations (Cayre et al. 2011). For example, poor accuracy of modeling is noticed as a source of error, in particular by simplifying assumptions about average, typical or expected behaviours or inexact quantifiable data (Lutzenhiser et al. 2010). The lack of accurate data, about insulation performance (Domínguez-Munoz et al. 2010) or concerning efficiency of equipment (Ertesvåg 2011), is also identified as a source of uncertainty.

Energy efficiency program

From 2006 onwards, EDF has conducted a regional energy efficiency program in France dedicated to the residential sector. It is not specially related with electricity end-uses but it covers also fuel end-uses. As this program was presented previously (Suerkemper et al. 2012), it will not be discussed in detail here. The main objective of this program is to generate substantial energy savings in the residential sector to achieve the associated benefits for households such as reduced energy bills and an increased level of comfort by providing advices, a skilled craftsmen network, soft loans and prerequisite grants.

To tackle the study of gaps between calculated energy consumptions and observed ones, a dedicated inquiry was conducted to some participants of this energy efficiency program.

Our analysis of inquiry results aims to understand sources of errors and to quantify them. What are these sources of errors? What is their origin? What are their effects? Can we explain a part of the after retrofitting error with the type of implemented energy efficiency measure, the bad workmanship or the change in set point temperature following the refurbishment?

Our objectives are also to observe whether after retrofitting errors are different from before retrofitting errors and to compare calculated energy savings with observed energy savings.

Method

The approach is based on a statistical analysis of deviations between the calculated consumptions, using an engineering modeling approach, and consumptions observed from a billing analysis. Firstly, this analysis is applied to the before retrofitting situation and secondly, to the after refurbishment situation in order to compare them and to separate the errors coming from the inquiry, the calculation and those linked to the energy efficiency measure(s) implemented.

Available data

The data were provided by two dedicated telephone surveys, during years 2009 and 2010 requiring household's information about their dwelling, their behaviour concerning space heating, the retrofitting actions done and the energy bills on the last three years.

The inquiry is based on a quota methodology to maximize the occurrence of less common retrofitting actions (e.g. wall or floor insulation) to the detriment of widespread actions (e.g. windows replacement, boiler). Finally, up to 167 questionnaires for the "before" situation, 81 for the "after" situation are usable for our study[1]. Among those, 50 are paired data presenting both situations (before and after refurbishment). The surveyed dwellings are solely consisting of old[2] single family housing mainly equipped with oil or wood boilers. The questionnaire is divided in 8 parts:

- Overall information: area, type and dwelling vintage, housing shape, orientation, etc.
- Insulation retrofitting: type (windows, wall, roof, floor), efficiency, materials used.
- Space heating energy (main and extra heater): space heating system (gas, oil, wood, LPG, electricity) and efficiency (standard, low temperature, condensing, heat pump, direct electric heating, etc.), energy management system, set point temperature before and after retrofitting, etc.
- Energy bills (electricity, wood, gas, LPG, fuel oil).
- Sanitary domestic hot water: energy used, type (instantaneous, accumulation, solar, etc.)

1 Initial sample was of 386 filled questionnaires.
2 Built before any thermal regulation (i.e.<1975).

- Ventilation: type (natural, mechanical, double flux, etc.), windows opening pattern, natural ventilation shaft (opened, closed, managed).
- Lighting and appliances: equipment, using pattern (inc. stand-by).

Concerning refurbishment measures, two types of action were included: those realized under the umbrella of the program and those realized outside the program (before or during the program). Thus, we must notice that more accurate information can be obtained for actions financed by the program while energy efficiency actions done before the program are less documented.

Energy consumption calculation (*ex-ante* evaluation)

The calculated consumption was estimated with a dynamic thermal model developed by EDF-R&D and based on *grey box* modeling by simplifying a complex model (Déqué, Ollivier & Poblador 2000). This software allows to calculate the energy consumption for all end-uses by using only 20 parameters (dwelling type, thermal losses, area, window area and orientation…).

This software was recently evaluated using an inquiry including 900 households, realized in 2009. The main results show for the whole building stock an error less than 5% between the sums of observed and calculated consumptions, due to the compensation of errors. Obviously, for a simple dwelling the error is much larger (up to 50% in extreme cases) (Allibe, Laurent & Osso 2010).

In spite of some limitations, the chosen model is consistent with the available information coming from the inquiry.

Input data to the model come either from the survey or they are default values in case of lack of information (e.g. the hours of wake-up and bedtime). For calculating consumption after retrofitting, the actions realized outside but during the program are taken into account[3] whereas the direct rebound effect is ignored.

Statistical analysis

Studying origin of deviations between observed[4] and calculated consumptions is done with a covariance analysis (ANCOVA), a general linear statistical modeling merging quantitative and qualitative variables.

The response variable of ANCOVA analysis is the natural logarithm of "likelihood ratio" (LR) between observed ($C_{obs.}$) and calculated ($C_{calc.}$) total consumptions (all end-uses) for each house:

$$\ln(LR_i) = \ln\left(\frac{C^i_{obs.}}{C^i_{calc.}}\right) = \ln\left(C^i_{obs.}\right) - \ln\left(C^i_{calc.}\right) \qquad \text{with i = before (b) or after (a) retrofit} \qquad \text{eq. 1}$$

Using the logarithm of (LR) helps to have a normal distribution for the model error. It is also convenient as the coefficients of the statistical model can be directly understood as percentage of (LR) variation. The variables used in the ANCOVA analysis are presented in the appendix (Table 5 and Table 6). In the aim to retain only the significant variables, a backward selection is applied with a significance level of 0.1. The constraint "sum of coefficients = 0" is used for the qualitative variables in order to avoid to choose an arbitrary category as a reference[5]. For all presented models, it is verified that:

- explanatory variables do not present colinearity (Variation Inflation Factor ≤ 3),
- residuals are homoscedastic (graphic verification),
- residuals are normally-distributed (Jarque-Bera test).

3 On the 81 dwellings, 26 (32%) have done at least a further action than these of the program.

4 Assessed from a billing analysis without end-uses breaking up.

5 Usually, one of the categories for each qualitative variables is chosen as a reference. Thus, the constraint is either "coefficient of the first category = 0" or "coefficient of the last category = 0". Then, the resulting model is dependent on the categories coding.

Results

Results are presented in two sections concerning before and after refurbishment situations. Each section is also split in two sub-sections: statistical description of the data and statistical modeling. The section dedicated to the "before" situation is presented in order to identify the sources of errors not correlated with the energy efficiency measure(s) implemented whereas the section dealing with the after retrofitting situation was aiming to evaluate the source of errors linked with the energy efficiency measure(s) (i.e. type of refurbishment, bad workmanship, set point temperature change).

Before refurbishment situation

Descriptive analysis. To assess the accuracy of the engineering modeling, the error ratio (ΔC_i) is calculated following equation below:

$$\Delta C_i = \frac{\left(C^i_{obs.} - C^i_{calc.}\right)}{C^i_{calc.}} \quad \text{with i = before (b) or after (a) retrofit} \qquad \text{eq. 2}$$

Generally speaking, the calculation method overestimates ($\Delta C_b<0$) the consumptions (Figure 1).The mean of error ratio has a value of -0.21, meaning that observed consumptions are, on average, lower by 21% than calculated consumptions[6]. Moreover, we must notice that extreme error cases exist with an error ratio larger than ±50%. Nevertheless, the majority of 167 cases studied (between 1st and 3rd quartiles) are included in a range from -41% to -3%. Furthermore, overestimation increases with high observed consumptions.

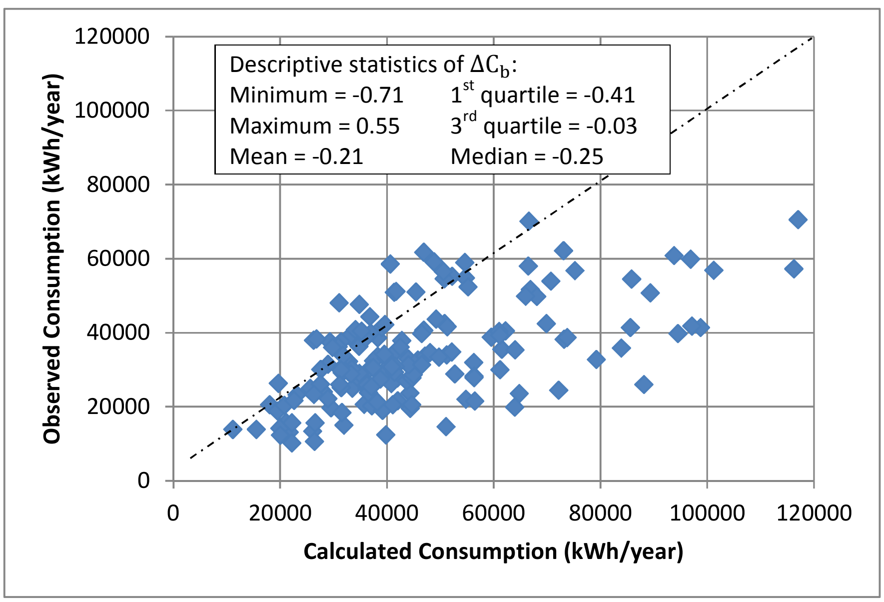

Figure 1. Observed and calculated consumption (all end-uses) before retrofitting of 167 individual houses. *Dotted line is the diagonal showing equivalence between observed and calculated consumptions.*

Statistical Model. The backward selection process of the ANCOVA analysis of $\ln(LR_b)$ (eq. 1) identifies the statistically significant variables among the initial explanatory variables (6 quantitative and 22 qualitative; see Table 5 in appendix for definition). ANCOVA results are

6 Depending on the equation, the calculated consumptions are on average higher by 44% than the observed consumptions.

presented in Table 3. The model is highly significant ([Pr > F] < 0.0001)[7], but its explanation and prediction capacity remains limited (adjusted R^2 = 0.482; Root-Mean-Square Error (RMSE) = 0.256). The negative intercept means that, on average[8], the calculated consumption is higher than the observed consumption $\left[\left(\ln\left(C_{obs.}^{b}\right) - \ln\left(C_{calc.}^{b}\right)\right) < 0\right]$ or $LR_b = \frac{C_{obs.}^{b}}{C_{calc.}^{b}} < 1$.

Moreover, the sign of coefficients helps us to identify the way how LR_b goes from the intercept value and so the gap between observed and calculated consumptions. As long as the sum of "the intercept value and the coefficient" is less than zero: with a negative sign, LR_b decreases and so the gap increases ($C_{calc.}^{b}$ moves away from $C_{obs.}^{b}$), while with a positive sign, LR_b increases so the gap is reduced ($C_{calc.}^{b}$ gets closer to $C_{obs.}^{b}$).

To clearly understand the meaning of the coefficients, we describe how to interpret the coefficients for two examples, a quantitative variable and a qualitative variable. Other coefficients will be analyzed in "Discussion" section below.

As an example of quantitative explanatory variable, we use the wood extra heater consumption. The positive coefficient (0.026) (Table 3, column "value") means that the LR_b increases of 2.6% when the wood extra heater consumption increases of 1 reference unit (i.e. 1 stere[9] in this example). Thus, the gap between the observed and the calculated consumptions decreases with the increase of the wood extra heater consumption.

For qualitative variables, meaning of the coefficients is slightly different, only the difference between the categories can be interpreted (constraint "sum of coefficients = 0"). As an example, we present the building vintage with the following coefficients (Table 3, column "value"): -0.121 for "houses build before 1974" and 0.121 for "houses build after 1981". This signifies that, *ceteris paribus,* a house built before 1974 has, on average, a LR_b lower of 24.2% than a dwelling built after 1981. The gap between observed and calculated consumptions for a house built before 1974 is higher than the gap for a house built after 1981.

Table 3. Qualified variables from the ANCOVA model of $\ln(LR_b)$ (sample=167, [Pr > F] < 0.0001, adjusted R^2 = 0.482, RMSE = 0.256).

Source of parameter (reference unit)	Value	Significance (Pr > |t|)
Intercept	-0.364	< 0.0001
ΔFloor area (10 m²)	-0.015	< 0.0001
Wood extra heater consumption (1 stere)	0.026	< 0.0001
ΔSet point temperature (1°C)	-0.028	0.028
Building vintage - before 74	-0.121	0.0002
Building vintage - after 81	0.121	0.0002
Insulation walls - no prior retrofitting, lower than insulation level of the building vintage	-0.221	0.003
Insulation walls - no prior retrofitting, insulation level of the building vintage	-0.122	0.002
Insulation walls - no prior retrofitting, higher than insulation level of the building vintage	0.119	0.004
Insulation walls -prior retrofitting	0.224	< 0.0001

7 The Fischer's F test checks the overall significance of the model. Since the probability associated with F is less than 0.0001, it means that the risk of error is less than 0.01% by concluding that the explanatory variables provide a significant amount of information to the model.
8 A house of 140 m² with the average characteristics of the selected categories (qualitative variables), a set point temperature of 19°C and without consumption of wood for extra heater.
9 1 stere corresponds about to 1710 kWh.

Type of floor - partial basement	0.119	0.009
Type of floor - total basement	0.085	0.033
Type of floor - crawlspace	-0.204	0.001
Type of loft - loft converted	0.099	0.013
Type of loft – without virgin loft	-0.099	0.013
Garage – no garage	-0.092	0.002
Garage- existence of a garage	0.092	0.002
Heating system – direct electric heating	-0.091	0.080
Heating system – old wood boiler	0.091	0.080
Management of set point temperature - never of reductions	-0.076	0.034
Management of set point temperature - during day and night	0.076	0.034

After retrofitting situation.

Descriptive analysis. With our sample of 81 cases in after retrofitting situation, calculated consumption is overestimated with the same order of error than before retrofitting situation (according to eq. 2, mean[10] of $\Delta C_a = -0.21$). Furthermore, with the paired sample of 50 cases[11], we have studied the error realized on the energy savings (Figure 2) following equations:

$ES_j = C_j^b - C_j^a$ with j= obs. or calc. and b=before, a=after retrofit eq. 3[12]

and $\Delta ES = \frac{(ES_{obs.} - ES_{calc.})}{ES_{calc.}}$ eq. 4

The calculation method also overestimates energy savings ($\Delta ES<0$). The observed energy savings are, on average, 23% lower than the calculated energy savings. We notice that the extreme errors are frequent (for 25% of the cases the gap between observed and calculated energy savings are higher than calculated savings).

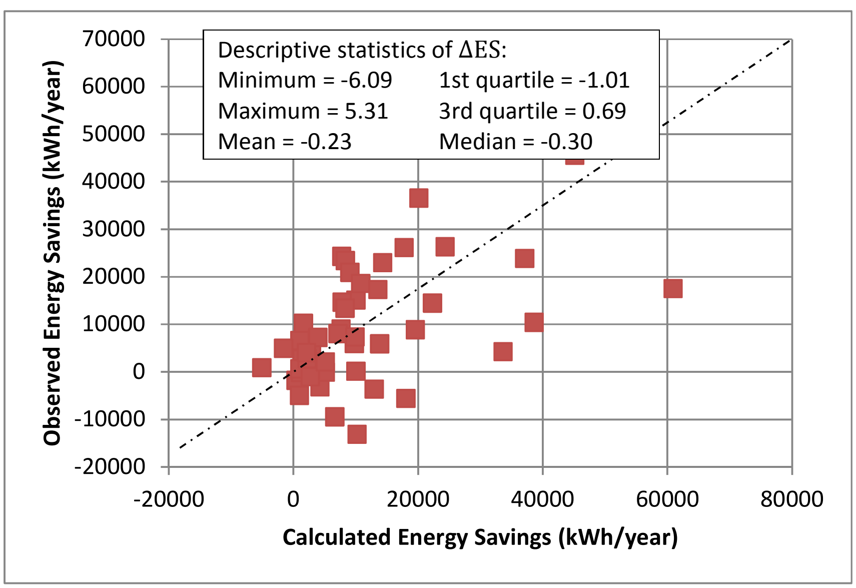

Figure 2. Observed and calculated energy savings of 50 individual houses. *Dotted line is the diagonal showing adequacy between observed and calculated energy savings.*

10 Descriptive statistics of ΔC_a: No. of observations = 81, Minimum = -0.65, Maximum = 0.40, 1st quartile = -0.41, 3rd quartile = -0.06 and Median = -0.24.

11 This sample of 50 cases is the result of the union of the "before" (167 cases) and "after" (81 cases) samples.

12 The consumptions used are not climate adjusted.

Statistical Model. The ANCOVA analysis of $\ln(LR_a)$ (eq. 1) supplies a significant model ([Pr > F] < 0.0001) with a still limited explanation capacity (adjusted R^2 = 0.370; RMSE = 0.237). Among the statistically significant variables kept by the selection procedure (among 6 quantitative and 17 qualitative variables[13]; see Table 6 in appendix for definition), only the variable "set point temperature change" (value = 0.063, significance (Pr > |t|) = 0.015) is a variable directly linked with the refurbishment. The variables "energy efficiency action" and "bad workmanship" are not significant from statistical viewpoint. The rest of this model[14] is not presented because it does not provide more information than the previous ANCOVA model of $\ln(LR_b)$.

Unfortunately, the paired sample with energy consumption after and before retrofitting, with its small size (50), does not enable to perform a similar multivariate statistical analysis for energy savings.

Discussion

First, looking at differences between observed and calculated energy consumptions, we can note that after retrofitting errors have the same order of magnitude than before retrofitting errors. In the two situations, observed consumptions are, on average, lower by 21% than calculated consumptions. Moreover in both cases, three-quarters of the samples present an overestimated calculations (3rd quartile <0). Comparing observed and computed energy savings, despite of a limited paired sample, provides fully consistent results: observed energy savings are, on average, 23% lower than calculated energy savings.

Therewith, we must remark on the one hand, that extreme cases have very important gaps (gaps are several times the calculated values) and on the other hand, that these cases are frequent (for 25% of the cases, the gap between observed and calculated energy savings is higher than the calculated savings). To finish with this analysis, we have to notice that we have taken into account in the calculation the actions realized outside during the program[15], this operation is not always possible during an *ex-ante* evaluation. Without that, the gap would be underestimated or inversed (observed energy savings higher than calculated ones) due to overestimation of the observed energy savings attribute to the only action(s) of the program. Finally, overestimation by computation, both for consumptions and energy savings, is an expected result from literature.

Now, we will try to understand the sources of errors between calculations and observations. The sources of errors can come from different origins: modeling, inquiry or both. Thus, we will base our analysis on this classification.

Some errors identified by the statistical model can be attributed to modeling flaw, such as wood extra heater consumption, building vintage, floor type and existence of a garage. The gap between observed and calculated consumptions is reduced with the increase of wood extra heater consumption (the LR_b increases of +2.6% by stere). In this situation (extra wood boiler), the model does not evaluate wood consumption but the value given by the household is an input variable to the model. So, a part of the energy consumption is supplied to the model, leading to smaller error. However, this is true until the sum "the intercept value + (the coefficient * the wood extra heater consumption)" is less than zero, *i.e.* in the average situation[16] until a wood consumption of 14 steres. For bigger wood consumptions, calculated consumption becomes less than observed one and so the

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13 In comparison with the explanatory variables of the before retrofitting situation (Table 5 in appendix), some modifications have been realized mainly to avoid colinearity problems. The variable "set point temperature change" is added while the variable "ΔSet point temperature" is removed. The variable "energy efficiency action" is added while the variables "windows", "insulation walls", "insulation floor", "insulation loft", "ventilation", "heating system" and "type of sanitary domestic hot water production" are removed. For finish, the variable "bad workmanship" is added.

14 The intercept has a value = -0.348 and a significance level is (Pr > |t|) <0.0001.

15 On the 50 dwellings, 10 (20%) have done at least a further action than these of the program.

16 See footnote 8.

gap increases. The error seems linked to a conflict in modeling between energy consumption of principal heating system and extra heater consumption. About the age of the building, the calculation model leads to bigger errors, rather strongly (LR_b variation = -24.2%). This is more visible for old houses (before any thermal regulation, so with higher variability of house typologies) than for recent houses. In the same way, the model presents more error for a floor above crawlspace than a floor above basement (partial and total). In the case of a garage, the evaluation error is lower (LR_b variation = +18.2%) than the case without a garage. This observation argues for an overestimation of the thermal losses by the model when there is no garage (the majority of the sample).

The error assumed to come from inquiry is the loft type because some households have a misunderstanding of the question or a complex situation which do not allow to supply to the calculation model a safe description of the loft type[17].

The remaining of modeling errors comes from both calculation and inquiry. The statistical model highlights that higher floor area (> 140 m²) leads to wider gap between observed and calculated consumptions (LR_b variation = -1.5% by additional 10 m²). This result shows the limit of a monozone model (by default, the whole house is heated at the mean set point temperature) for the houses with high surface. Actually, higher floor area corresponds to more complex energy management (e.g. entire dwelling not heated). But taking into account the energy management patterns would require more information concerning household behaviour, likely difficult (or even impossible) to gather.

Regarding the effect of average set point temperature, it is shown that higher values (difference with 19°C >0) lead to a more important gap between observed and calculated consumptions (LR_b variation = -2.8% by additional °C). The highest set point temperatures declared are probably linked to situations of localized over-heating associated with the presence of an extra heater in the living room (e.g. wood stove). In such cases, set point temperature declared by the household presents a high level of uncertainty and is poorly representative both spatially and timely. Nevertheless, the source of this error does not come only from the inquiry; the monozone model is particularly unsuitable when temperatures are highly heterogeneous between the rooms.

The influence of wall insulation on the ”likelihood ratio” before retrofitting is significant. Prior retrofitting of the house implies that the gap between observed and calculated consumptions is lower than in cases without a retrofitting. Households who have made prior retrofitting know more accurately existing wall insulation. In a second time, the statistical study shows that taking insulation levels depending on building vintage, as done by the calculation model, leads to overestimate thermal losses (LR_b variation = +34.6% between the categories “insulation level of the building vintage” and “prior retrofitting”).

The variable “management of the set point temperature” highlights that model overestimation is more reinforced when any reduction of the set point temperature is declared, than when reductions during the day and the night are declared (LR_b variation = -15.2%). Moreover, the households should have some difficulties to answer without uncertainty to this type of question (their behaviour may change during the heating season). However, the calculation model does not permit to vary the energy management (it only allows a single behaviour pattern during all the heating season).

Finally, the type of heating system presents a signification level lower than previous variables ([Pr > |t|] = 0.08). The model is more biased for houses with direct electric heating than houses with old wood boiler (wood log). On the one hand, the efficiency of old wood boiler used by the calculation model (between 0.5 and 0.55 depending on the power) could be too high and on the other hand, the wood consumption declared by the households (expressed in stere) is probably associated with a large uncertainty (no bill, self-estimate).

Concerning of the data sample after retrofitting, we concentrated the analysis on explanatory variables directly related to refurbishment. The statistical analysis of the “likelihood ratio” after retrofitting shows the lack of systematic error linked to the type of the energy efficiency action and

17 The houses with the category « without virgin loft » are modeled as houses with a loft converted.

the bad workmanship. The only significant variable of the model connected to refurbishments is the "set point temperature change"[18]. The gap between observed and calculated[19] consumptions is reduced when increasing this parameter (the LR_b increases of +6.3% by additional °C after retrofitting). Logically, with a perfect model, the change in set point temperature (no taking into account in calculations) should cause an underestimation by the model of observed consumption but we observe the opposite. This result argues for a modeling flaw and more precisely an overestimation of the thermal losses by the model. However, we cannot ignore that the "before" and "after" set point temperatures declared by the household presents a high of uncertainty level.

Conclusion

Firstly, this study has shown that modeling overestimates consumptions with the same order of magnitude before and after retrofitting. Calculated energy savings are also overestimated; a number of cases present an important gap between calculated and observed values (gap is at least one time the calculated value).

Then, it has been seen that the main sources of errors between *ex-post* and *ex-ante* evaluations depend on the one hand, on the only modeling methodology and on the other hand, on an association of the modeling methodology with the quality of inquiry. Among errors linked with the only modeling methodology, we find the building vintage and in particular, the recurrent difficulty of models to take into account the oldest houses (built before any thermal regulation). Concerning errors based on modeling methodology and quality of inquiry, the limit of simple modeling (e.g. monozone simulation) must be noticed but this is linked to the deepness of the inquiry that should be able to provide more data for a detailed model. Thus, the level of detail of both inquiry and model needs to be in accordance. Unfortunately, households have limited energy efficiency skills and questioning them about particular technical topics is difficult. Moreover, households aren't able to answer very precisely about their behaviours as some are not aware of (i.e. routine) or their memory is altered by the time. The alternative way to have better information level, on-site energy audits and monitoring, could not be spread at large scale due to high cost.

To finish, it has been highlighted that differences between *ex-post* and the *ex-ante* evaluations in the after retrofitting situation do not seem to be linked with the type of energy efficiency action and the bad workmanship. Only the change in set point temperature due to the refurbishment has an influence, but the observed effect (the error decreased with an increase of set point temperature after retrofitting) does not go to the logically expected direction. This seems at least partly caused by a modeling flaw.

For future works, we hope to enhance the validity of those results by an increase of the samples from a new survey dedicated to insulation measures already done (in 2011) but not exploited here due to time constraint.

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18 On the 81 cases, 64 households do not declare an change in set point temperature (between 17.25 °C and 25 °C) while 14 declare have increased the set point temperature after retrofitting (between +1 °C and +3.75°C with the initial set point temperatures between 17°C and 20 °C) and 3 declare have decreased the set point temperature (between -2 °C and -5 °C with the initial set point temperatures between 22°C and 25°C).

19 For reminder, the calculation is done without taking into account the set point temperature change.

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Appendix

Table 5. Explanatory variables used for the statistical model of $\ln(LR_b)$ (sample "before"=167).

Variable	Definition
Quantitative variables	
ΔHDDs	Difference between the actual and the normative numbers of annual regional heating degree days; reference unit: 100 HDDs; [-5.47; -3.52]
ΔFloor area	Difference between the floor area and 140 m² (mean of the sample); reference unit: 10 m²; [-8.2; 20.8]
ΔHeight	Difference between the ceiling height and 2.5 m (mean of the sample); reference unit: 1 m; [-0.5; 2.2]
ΔElectrical appliances	Difference between the number of electrical appliances declared and 14 (mean of the sample); reference unit: 1 electrical appliance; [-6.0; 8.0]
Wood extra heater consumption	Yearly wood extra heater consumption; reference unit : 1 stere; [0.0; 30.0]
ΔSet point temperature	Difference between the set point temperature and 19 °C; reference unit : 1 °C; [-3.5; 6.0]
Qualitative variables and their categories	
Building vintage	0- before 1974 (67.7% of the sample); 1- between 1974 and 1976 (10.2%); 2- between 1977 and 1981 (6.6%); 3- after 1981 (15.5%)
Windows	0- no prior retrofitting declared (55.1% of the sample); 1- prior retrofitting declared (44.9%)
Insulation walls	0- no prior retrofitting declared and a insulation level declared lower than the insulation level of the building vintage (4.8% of the sample); 1- no prior retrofitting declared and a insulation level declared equals to the insulation level of the building vintage (34.1%); 2- no prior retrofitting declared and a insulation level a insulation level declared higher than the insulation level of the building vintage (28.1%); 3- prior retrofitting declared (33.0 %)
Insulation floor	0- no prior retrofitting declared and a insulation level declared lower than the insulation level of the building vintage (22.1 % of the sample); 1- no prior retrofitting declared and a insulation level declared equals to the insulation level of the building vintage (58.7%); 2- no prior retrofitting declared and a insulation level a insulation level declared higher than the insulation level of the building vintage (9.0%); 3-prior retrofitting declared (10.2%)
Insulation loft	0- no prior retrofitting declared and a insulation level declared lower than the insulation level of the building vintage (22.1 % of the sample); 1- no prior retrofitting declared and a insulation level declared equals to the insulation level of the building vintage (10.2%); 2- no prior retrofitting declared and a insulation level a insulation level declared higher than the insulation level of the building vintage (30.0%); 3- prior retrofitting declared (37.7%)
Ventilation	0- no prior retrofitting declared (86.8% of the sample); 1- prior retrofitting declared (13.2%)
Type of floor	0- partial floor above basement (18.0% of the sample); 1- total floor above basement (53.9%); 2- floor above ground (21.5%); 3- floor above crawlspace (6.6%)
Type of loft	0- loft converted (22.1% of the sample); 1-virgin loft (70.7%); 2- without virgin loft (7.2%)
Common ownership	0- house separate (67.6% of the sample); 1- existence of one party wall (17.4%); 2- existence of least two party walls (15%)
Garage	0- no garage (79% of the sample); 1- existence of a garage (21%)
Form	0- house with a compact form (73.6% of the sample); 1- complex form (26.4% of the sample)
Orientation windows	0- majority to the south (58.7% of the sample); 1 - majority to the north (17.4%); 2 - as much to the south as to the north (23.9%)
Storey	0- no storey (31.7% of the sample); 1- existence of least one storey (68.3%)
Heating system	0- direct electric heating (22.7% of the sample); 1- boiler (all energies except wood) installs before 2002 (62.9%); 2- boiler (all energies except wood) installs after 2001 (7.8 %); 3- old wood boiler (6.6%)
Type of sanitary domestic hot water production	0- electric water heater (49.1% of the sample); 1- via boiler with tank (39.5%); 2- via boiler without tank (11.4%)
Management of set point temperature	0- during week, never of reductions (32.3% of the sample); 1- reduction during night or day (59.9%); 2-reduction during day and night (7.8%)
Management of sanitary domestic hot water	0- only showers (59.3% of the sample); 1- showers and some baths (40.7%)
Lighting	0- majority of classic bulbs (31.1% of the sample); 1- majority of fluorescent bulbs (39.5%); as many classic bulbs as fluorescent bulbs (29.3%)

Cooking energy	0- electricity as main energy (27.5% of the sample); 1- gas as main energy (12.6%); 2- LPG as main energy (59.9%)
Swimming pool	0- no swimming pool (95.2% of the sample); 1- existence of a swimming pool (4.8%)
Time of open windows	0- less than 10 minutes per day (48.5% of the sample); 1- between 10 minutes and 30 minutes per day (29.9%); 2- between 30 minutes and 1 hour per day (11.4%); 3- more than 1 hour per day (10.2%)
Number of occupants during day	0- nobody during days of week (31.1% of the sample); 1- one person (30%); 2- two persons (38.9%)

Table 6. Explanatory variables used for the statistical model of $\ln(LR_a)$ (sample "after"=81).

Variable	Definition
Quantitative variables	
ΔHDDs	Difference between the actual and the normative numbers of annual regional heating degree days; reference unit: 100 HDDs; [-5.47;-2.17]
ΔFloor area	Difference between the floor area and 140 m² (mean of the sample); reference unit: 10 m²; [-6.2; 15.8]
ΔHeight	Difference between the ceiling height and 2.5 m (mean of the sample); reference unit: 1 m; [-0.5; 0.75]
ΔElectrical appliances	Difference between the number of electrical appliances declared and 14 (mean of the sample); reference unit: 1 electrical appliance; [-5; 9]
Wood extra heater consumption	Yearly wood extra heater consumption; reference unit : 1 stere; [0; 27]
Set point temperature change	Change in set point temperature due to the retrofitting; reference unit: 1°C; [-5.00; 3.75]
Qualitative variables and their categories	
Bad workmanship	0- no bad workmanship (90.1% of the sample); 1- bad workmanship (9.9%)
Energy efficiency action	0- action only on sanitary domestic hot water production (6.2% on the sample); 1- action only on insulation (8.6%); 2- action only on heating system (34.6%); 3-actions on several fields (50.6%)
Building vintage	0- before 1974 (74.1% of the sample); 1- between 1974 and 1976 (7.4%); 2- between 1977 and 1981 (7.4%); 3- after 1981 (11.1%)
Type of floor	0- partial floor above basement (17.3% of the sample); 1- total floor above basement (51.8%); 2- floor above ground (24.7%); 3- floor above crawlspace (11.1%)
Type of loft	0- loft converted (22.2% of the sample); 1-virgin loft (71.6%); 2- without virgin loft (6.2%)
Common ownership	0- house separate (64.2% of the sample); 1- existence of one party wall (21%); 2- existence of least two party walls (14.8%)
Garage	0- no garage (70.4% of the sample); 1- existence of a garage (29.6%)
Form	0- house with a compact form (71.6% of the sample); 1- complex form (28.4% of the sample)
Orientation windows	0- majority to the south (60.5% of the sample); 1 - majority to the north (8.6%); 2 - as much to the south as to the north (30.9%)
Storey	0- no storey (25.9% of the sample); 1- existence of least one storey (74.1%)
Management of set point temperature	0- during week, never of reductions (30.9% of the sample); 1- reduction during night or day (61.7%); 2- reduction during day and night (7.4%)
Management of sanitary domestic hot water	0- only showers (45.7% of the sample); 1- showers and some baths (54.3%)
Lighting	0- majority of classic bulbs (23.5% of the sample); 1- majority of fluorescent bulbs (42.0%); as many classic bulbs as fluorescent bulbs (34.5%)
Cooking energy	0- electricity as main energy (25.9% of the sample); 1- gas as main energy (16.1%); 2- LPG as main energy (58%)
Swimming pool	0- no swimming pool (95.1% of the sample); 1- existence of a swimming pool (4.9%)
Time of open windows	0- less than 10 minutes per day (44.4% of the sample); 1- between 10 minutes and 30 minutes per day (27.2%); 2- between 30 minutes and 1 hour per day (18.5%); 3- more than 1 hour per day (9.9%)
Number of occupants during day	0- nobody during days of week (27.2% of the sample); 1- one person (39.5%); 2- two persons (33.3%)