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

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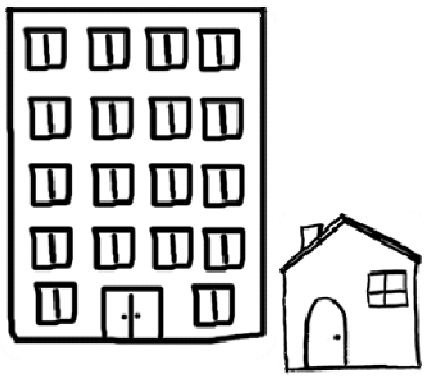


Context

⦿ In housing sector:

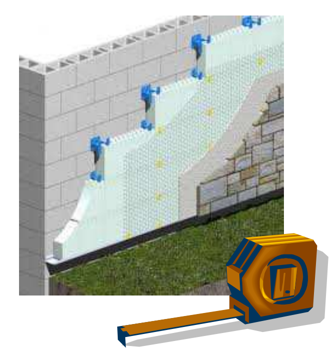
- At EU level, mainly ***ex-ante* evaluations** of energy savings and few *ex-post* evaluations
- **Overestimation** of energy consumptions and energy savings calculated by engineering models (Branco et al. 2004, Hens 2010, Hong et al. 2006)
- Sources of errors: simplifying assumptions about **behaviour** (Cayre et al. 2011) or **inaccurate data** (Lutzenhiser et al. 2010)

⦿ Our approach:

- **Statistical modeling** of deviations between calculated

and observed consumptions **before and after refurbishment**

on a panel of retrofitted dwellings in France



Aims of the study

⦿ To give answers to the following questions:

- What are **sources of errors** between calculated and observed consumptions? Where do they come from? What are their effects?
- **Can we explain** part of **after retrofitting error** with variables linked to refurbishment (*i.e.* type of measure implemented…)?
- Are **errors different after** retrofitting from ”**before**” ?

Presentation

The data employed

The methods used

The results obtained

The conclusions drawed

The program studied…
and the dedicated inqu

- The EE program (Suerkemper et al. 2012):
  - A **regional energy efficiency program** in France
  - Conducted by EDF from 2006
  - Covering **electricity and fuel end-uses** in the residential sector
  - At the end of 2011, more than 10000 retrofitting measures implemented

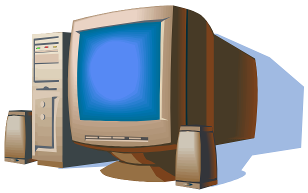
- The inquiry:
  - Two telephone surveys during 2009 and 2010
  - Informations required: building typology, energy systems, behaviour, retrofitting action(s) (with and outside the program), **total energy bills** (on the last three years)
  - 386 filled questionnaires

The samples

- Type of dwellings: **old** (<1974) **single family housing** mainly initially equipped with **oil or wood boilers**
- Type of refurbishment: insulation, double glazing windows, solar hot water heating, wood stoves or boilers, condensing boilers, heat pumps and multiple actions

- 167 questionnaires for the ”before” situation (pre-retrofit)
- 81 questionnaires for the ”after” situation (post-retrofit)
- 50 questionnaires presenting both situations (”before” and ”after ”)

Ex-ante and *ex-post* evaluations



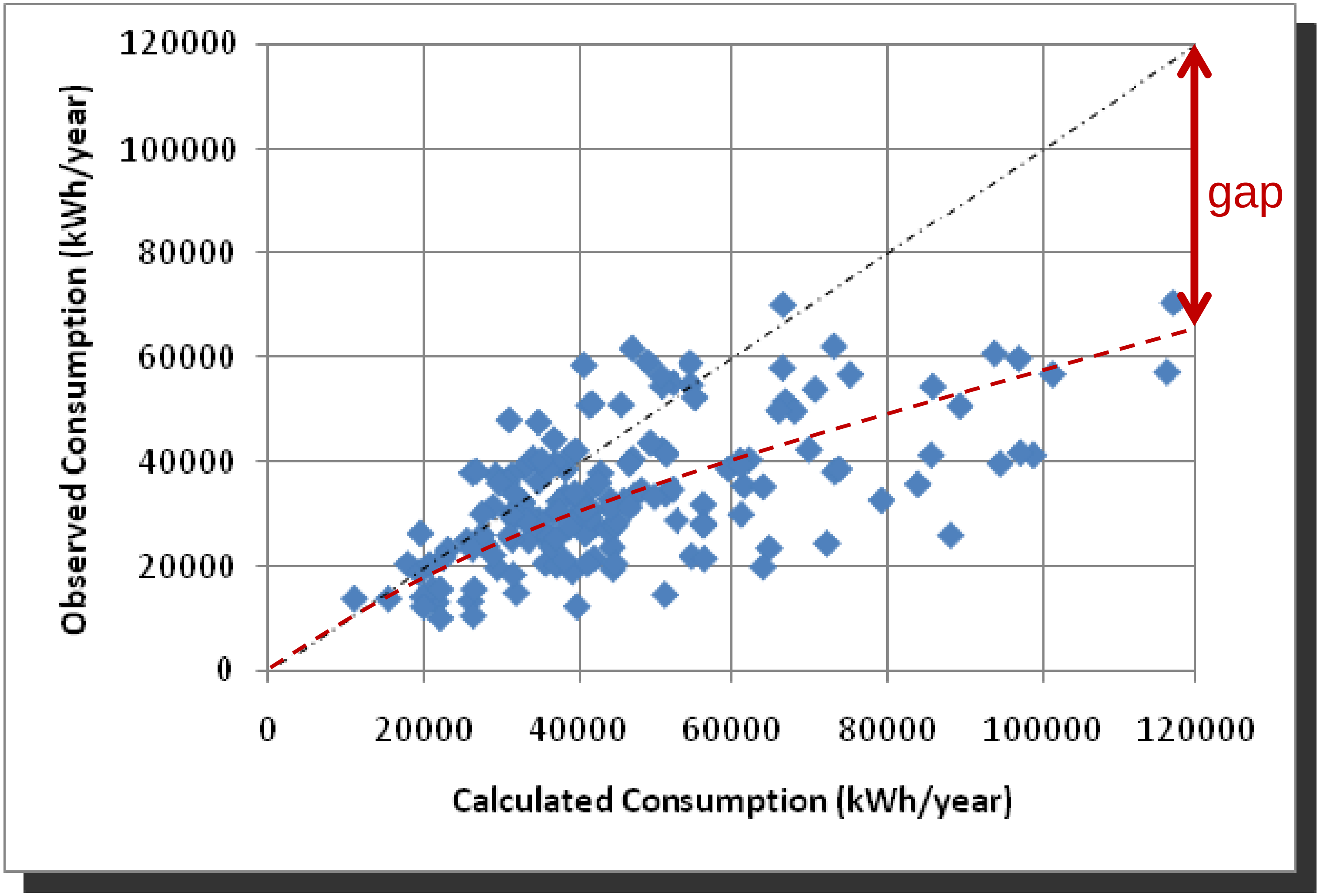
- ***Ex-ante* (Engineering model)** (Déqué, Ollivier & Poblador 2000):
  - A dynamic thermal model (monozone) developed by EDF-R&D
  - Simulation of energy consumption for **all end-uses**

- Input data to the engineering model:
  - From the inquiry or default values (*e.g.* the hours of wake-up)
  - Modeling of the “after” situation <u>without</u> the direct rebound effect (no temperature change)

- ***Ex-post* evaluation**:
  - **Billing analysis** (electricity, wood, gas, LPG and fuel oil)

Descriptive analysis

- Before refurbishment situation:

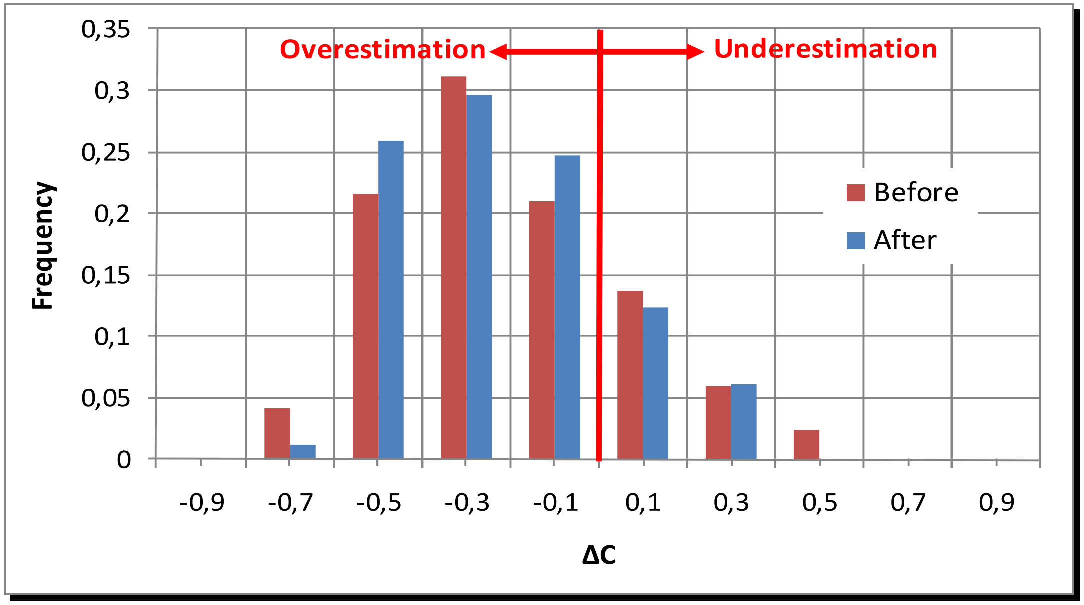


Descriptive analysis

- The error ratio: $\Delta C_i = \frac{(C^i_{obs.} - C^i_{calc.})}{C^i_{calc.}}$ with i = before (b) or after (a) retrofit

- Comparison between after retrofitting and before retrofitting errors:

Situation	Before ΔC_b	After ΔC_a
1st quartile	-0.41	-0.41
Median	-0.25	-0.24
3rd quartile	-0.03	-0.06
Mean	-0.21	-0.21



➢ **Same order of magnitude** for errors: (21%)

Analysing the gap with a statistical model

- The **response** variable:

$$\ln\left(\frac{C^{i}_{obs.}}{C^{i}_{calc.}}\right) = \ln\left(C^{i}_{obs.}\right) - \ln\left(C^{i}_{calc.}\right)$$

With $C_{obs.}$= observed total consumption (in kWh/year), $C_{calc.}$= calculated total consumption (in kWh/year) and i = before (b) or after (a) retrofit

- The **explanatory** variables:
- Variables about: **building, systems, climate, socioeconomic, behaviour and retrofit**
- For the “before” situation, 28 variables
- For the “after” situation, 23 variables

Statistical method used

- Quantitative and qualitative variables → **covariance analysis** (ANCOVA, general linear statistical modeling)
- **Backward selection** to retain only the significant variables with at least a significance level of 0.1 on Student's test
- Reference of the quantitative variables with the constraint «sum of coefficients = 0»
- 2 statistical models:
  - Model of ln(ratio **before retrofitting**) with a sample of 167 cases
  - Model of ln(ratio **after retrofitting**) with a sample of 81 cases

Model of ln(ratio before retrofitting)

$$\ln\left(\frac{C^b_{obs.}}{C^b_{calc.}}\right) = \ln(C^b_{obs.}) - \ln(C^b_{calc.})$$

- Quality of model:

Model highly significant (Pr to Fisher's test <0.0001)

Explanation and prediction capacities limited (adj. $R^2 = 0.482$; RMSE* = 0.256)

- Negative intercept (-0.364) → On average, the calculated consumption is higher than the observed consumption

- **Classification of variables** in three sources of errors:
  - coming from modeling
  - coming from inquiry
  - coming from interaction between modeling and inquiry

* RMSE= Root-Mean-Square Error

Model of ln(ratio before retrofitting)

$$\ln\left(\frac{C^b_{obs.}}{C^b_{calc.}}\right) = \ln(C^b_{obs.}) - \ln(C^b_{calc.})$$

- Errors coming from modeling flaw:
  - Building vintage (high significance): After 1981 ➔ Before 1974 → Gap ↗
  - Garage (high significance): With ➔ Without → Gap ↗
- Errors coming from inquiry:
  - Loft type (high significance): Converted loft ➔ Without virgin loft → Gap ↗

Model of ln(ratio before retrofitting)

$$\ln\left(\frac{C^b_{obs.}}{C^b_{calc.}}\right) = \ln\left(C^b_{obs.}\right) - \ln\left(C^b_{calc.}\right)$$

- Errors coming from interaction between modeling and inquiry:

- Floor area (high significance): m² ↗ ⇒ Gap ↗

- Wall insulation (high significance): Prior retrofitting ➡ No prior retrofitting ⇒ Gap ↗

+ insulation default values link to building vintage lead to an overestimation

Model of ln(ratio after retrofitting)

$$\ln\left(\frac{C^a_{obs.}}{C^a_{calc.}}\right) = \ln(C^a_{obs.}) - \ln(C^a_{calc.})$$

- Quality of model:
- Model highly significant (Pr to Fisher's test <0.0001)
- Explanation and prediction capacities limited (adj. $R^2 = 0.370$; RMSE = 0.237)

- Negative intercept (-0.348) ⇒ overestimation of calculated consumption

- Three variables directly linked with the refurbishment:
  - Type of energy efficiency action: not significant
  - Unskilled workforce: not significant
  - Declared temperature change: **high significance**

- Remaining variables don't provide more information than the "before" model

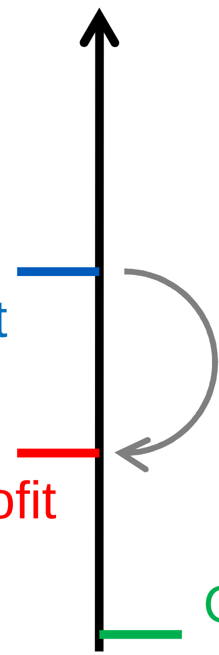
Model of ln(ratio <u>after</u> retrofitting)

$$\ln\left(\frac{C^{a}_{obs.}}{C^{a}_{calc.}}\right) = \ln(C^{a}_{obs.}) - \ln(C^{a}_{calc.})$$

- Declared temperature change (high significance):

Declared temperature after retrofitting ↗ ⇒ Gap ↘

Consumption
in kWh/year



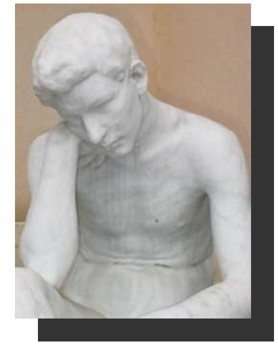
Calculated consumption **after** retrofit
with declared temperature **<u>After</u>** retrofit

T ℃ "after" > T° C "before"

Calculated consumption **after** retrofit
with declared temperature **<u>Before</u>** retrofit
(ex-ante evaluation)

Observed consumption **after** retrofit
at declared temperature **<u>After</u>** retrofit

Conclusions drawn



- **Engineering model overestimates** consumptions with the **same order of magnitude** before and after retrofitting

- The **main sources of errors** between *ex-post* and *ex-ante* evaluations depend on:

• Modeling flaw: recurrent difficulty to take into account the oldest houses

• Interaction between modeling and inquiry: limits of simple modeling (monozone simulation) and uncertainty about declared informations

- The **errors** between *ex-post* and *ex-ante* evaluations in the **after retrofitting** :

• **Not found a link** with **type of energy efficiency action**

• A **link** with **temperature change** (proxy of direct rebound effect**):**

Effect doesn't go to the expected direction (compensation of modeling flaw)

Conclusions drawn (continuation)

- Future works:

- To enhance the validity of those results from new surveys dedicated to insulation measures and air/air heat pump implementation
- Statistical modeling of direct rebound effect

Many thanks for your attention !

Your comments and suggestions are welcome at:

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Appendix

- Explanatory variables used for the statistical model of $\ln(LR_b)$:
- 15 variables about building

Variable	Definition
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]
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 %)

Appendix

- Explanatory variables used for the statistical model of ln(LR_b) :
- 15 variables about building (continuation)

Variable	Definition
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%)

Appendix

- Explanatory variables used for the statistical model of $\ln(LR_b)$:
- 15 variables about building (continuation)

Variable	Definition
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%)

Appendix

- Explanatory variables used for the statistical model of $\ln(LR_b)$:
- 7 variables about systems

Variable	Definition
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]
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%)
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%)

Appendix

- Explanatory variables used for the statistical model of ln(LR_b) :
- 1 variable about climat

Variable	Definition
ΔHDDs	Difference between the actual and the normative numbers of annual regional heating degree days; reference unit: 100 HDDs; [-5.47; -3.52]

- 1 variable socioeconomic

Variable	Definition
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%)

Appendix

- Explanatory variables used for the statistical model of $\ln(LR_b)$:
- 4 variables about behaviour

Variable	Definition
ΔSet point temperature	Difference between the set point temperature and 19 °C; reference unit : 1 °C; [-3.5; 6.0]
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%)
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%)

Appendix

- Explanatory variables used for the statistical model of ln(LR_a) :
- 10 variables about building

Variable	Definition
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]
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%)

Appendix

- Explanatory variables used for the statistical model of $\ln(LR_a)$:
- 10 variables about building (continuation)

Variable	Definition
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%)

Appendix

- Explanatory variables used for the statistical model of ln(LR_a) :
- 5 variables about systems

Variable	Definition
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]
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%)

Appendix

- Explanatory variables used for the statistical model of $\ln(LR_a)$:
- 1 variable about climat

Variable	Definition
ΔHDDs	Difference between the actual and the normative numbers of annual regional heating degree days; reference unit: 100 HDDs; [-5.47;-2.17]

- 1 variable socioeconomic

Variable	Definition
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%)

Appendix

- Explanatory variables used for the statistical model of $\ln(LR_a)$:
- 4 variables about behaviour

Variable	Definition
Set point temperature change	Change in set point temperature due to the retrofitting; reference unit: 1°C; [-5.00; 3.75]
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%)
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%)

Appendix

- Explanatory variables used for the statistical model of ln(LR_a) :
- 2 variables about retrofit

Variable	Definition
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%)