INFLUENCE OF FIELDS DATA QUALITY ON THE MODELING OF RESIDENTIAL BUILDINGS WITH DYNAMIC SIMULATION TOOL

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ABSTRACT

To produce a realistic building reference's model, in order to work on a retrofitting project, input data have to be chosen with the field's information. The present work concerns French residential buildings of the pre-world-war-II family. This category is more and more subject to retrofitting project and represents more than 30% of the French building sector. In addition, the old buildings are characterised by difficulties to collect data.

The aim of this work is to identify the limits of modelling precision for energy simulation.

To achieve this objective, two buildings have been modelled, it consists on one house and one flat that were monitored and for which data have been recorded during a year. Moreover, for each input data, a field value and an uncertainty range are proposed. The output data analysis shows a hierarchical influence of the input data uncertainty.

INTRODUCTION

Dynamic thermal simulation of real building to work on retrofitting project is a common activity nowadays. Decisions on design are made thanks to these simulations. Different simulation tools are well known. The validations of these codes are published in the literature. Nevertheless, the question of the determination of the input data still exists for the user. Hopfe has shown the necessity to considerate the uncertainties of the model when decision making is based on simulation predictions (Hopfe, 2011).

The difficulties to assess some values and to be precise about stochastic scenarios can lead to a wide range of uncertainty on the input data. The results of the simulations depend on these sets of values coupled to uncertainties. So the comparison of simulations to real world outcomes may provide substantial differences.

Several authors investigate on the impact of the main uncertainties on the simulated energy consumption (Brohus, 2009) or on the indoor air temperature (Macdonald, 2001). Different methods of evaluation for these impact of uncertainties are available in the literature. Lomas compared differential sensitivity analysis, Monte Carlo analysis and stochastic analysis (Lomas, 1991). He concludes that stochastic analysis is the most complicated method to implement and can't be applied on all programs. The Monte Carlo analysis only gives the total sensitivity information and the differential sensitivity analysis gives both total and individual sensitivity with programs which can be assumed to operate as roughly linear. Macdonald tried the differential and the Monte Carlo analysis on ESP-r cases (Macdonald, 2001).

The aim of this paper is to identify the limits of modelling precision and therefore the limits in the comparison between simulation and real behaviour of traditional buildings.

A method to assess the modelling precision is applied to two different cases in this paper. To produce a realistic model of the reference cases for these buildings, field data can be collected. For that purpose, construction plans, surveys with the inhabitants, energy consumption and indoor temperature measurements, blower door tests and others actions could be used. The two buildings have been selected in a field measurements campaign (Cantin, 2010) of a previous project. Both are pre world war II French building, a flat and a house. This family of old building represents more than 30% of the French building sector and is a real stake for energy savings and retrofitting with heritage consideration. Another particularity, object of this paper, is the large uncertainties in the characteristics of these buildings. So, the buildings cases are presented, then the method to assess the local and global sensitivity and conclusions are made about the modeling of old buildings.

METHOD AND RESULTS

Data collection

The data to be collected via the different possible ways are listed in table 1. They are needed as input data for the simulation program.

For both cases, data have been collected during a year. It consists of a monitoring with timestep of an hour, an occupancy survey, punctual investigations such as infrared thermography, plans drawing with rangefinder measurements. A dynamic code has been used to model these buildings. The thermal model is an hourly time step for all uses. The calculation of heating and cooling needs is based on detailed algorithms implementing European standard, ISO 13790 (ISO, 2008). It is based on the simplification of the heat transfer between indoor and external environment. A 5RC equivalent electric representation of the building component is used (Videau, 2013).

table 1: Data collection for the entries of the model

U-values walls	U values windows
g-value windows (solar energy transmittance of glass)	Architectural masks
Environnement masks	Thermal bridges ψ
Correction coefficient for thermal losses through walls in contact with non-heated space "b"	Schedule of windows opening and corresponding airflow rate
Mechanical ventilation airflow rate	Schedule for blinds
Occupants internal gains	Other internal gains (including electrical devices such as lighting,…)
Measured indoor temperature	Inertia class *
Orientation	Infiltration rate **
Solar radiation	Outdoor air temperature
Wind speed	Sky temperature
Glazing surfaces	Surfaces of opaque walls
Thermal bridges lenght	Solar factor opaque walls

*The simulation program uses classes for thermal inertia, from very light to very heavy, like the French thermal regulation rules.

**The blower door measurement gives access to an estimation of the infiltration through the walls, ceiling and floor of the flat/house.

Buildings description

The first case is an apartment building in the center of Paris illustrated on the figure 1. Its architecture is typical from the 1851-1914 period. This type of building represents 29% of the centre of Paris (Apur, 2011). The flat on the fifth floor (the one with the long balcony on the middle on figure 1) has been studied. The figure 2 presents the plan of the flat.

figure 1: Façade of the building in Paris

The surface of the flat is 108 m² and it has boundaries with another occupied flat below, on the south-west and on the north-east side. The upper flat is unoccupied. The north-west façade is on a courtyard (room 4, 6 and 7) and the south-east façade (room 8, 9, 10 and 11) is on the street.

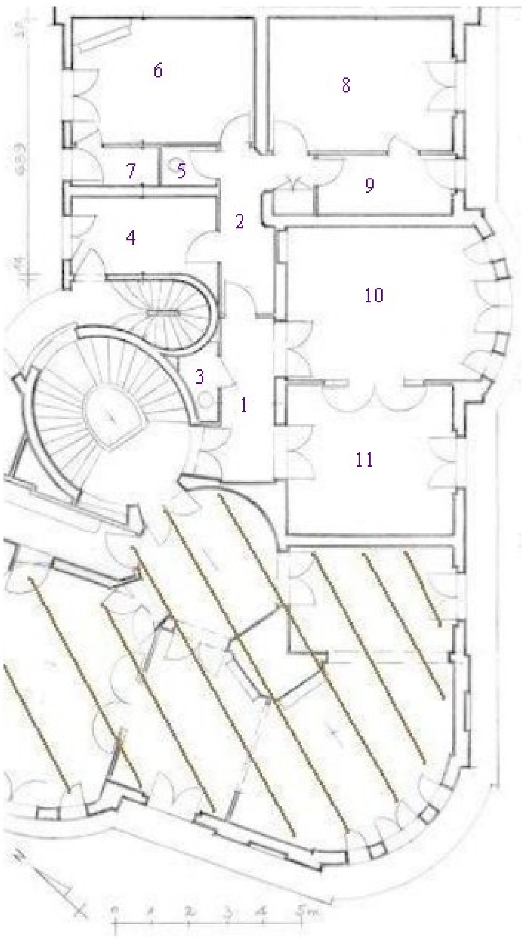

figure 2: Plan of the studied flat

To illustate the uncertainties and the special care specific in traditional buildings, a focus on the U-value of the ceiling is presented. The figure 3 is a drawing of the situation. It consists of a oak parquet on joists support by orthogonal iron beams. There is an air gap between the joists and between the beams, the cavity is closed by a wood lathing and a plaster layer.

The code Heat 3 by Blocon has been used to perform the U-value calculation for the whole ceiling with the uncertainties. The table 2 gives the results when the thickness of each layer is considered without uncertainties. For this configuration of floor, the calcul gives 1,33 W/(m².K) more or less 10%. Another characteristic of the ceiling in this family of buildings is the punctual bonds with the vertical walls. Infrared study shows no thermal bridges (Cantin, 2010).

table 2: U-value of the ceiling of the appartment

	Estimated value	Minimun value	Maximum value
Oak thermal conductivity	0,20 W/(m.K)	0,17 W/(m.K)	0,23 W/(m.K)
Plaster coating thermal conductivity	0,45 W/(m.K)	0,3 W/(m.K)	0,6 W/(m.K)
Air gap equivalent thermal resistance	0,146 m².K/W	0,138 m².K/W	0,153 m².K/W
U-value for the ceiling	1,33 W/(m².K)	1,19 W/(m².K)	1,45 W/(m².K)

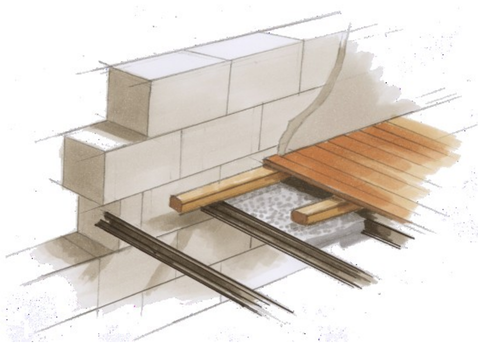

figure 3: Conception of the Parisian buildings floor/ceiling in the second part of the 19th century.

The second study case is a semi-detached house from around 1930 (figure 4). The floor surface is 106,2 m², 97 m² without the attic (which is a sleeping room). The main orientation is North on the garden. So, the street is the west side. The house is composed of a basement and two floors as shown in the figure 5. The main features of these two cases are summerized in the table 3.

figure 4: Studied house in Noisiel (East of Paris)

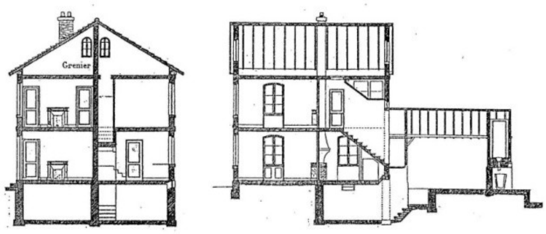

figure 5: section of the house

table 3: Main features of the two cases

Main features:	Flat	House
External walls	On the street : cut limestone + internal plaster coating, U = 2,08 W/(m².K) ±16%. On the courtyard : coating + rough stone + internal plaster coating, U = 1,49 W/(m².K) ±8%.	Coating + Bricks layout “à la Française” id est two layers with brick in both directions. + internal plaster coating, U = 1,93 W/(m².K)
b value *	For the upper floor : 0,74 ±0,03. For the staircase : 0,87 ±0,03.	For the contact with the garage: 0,89±0,03. For the first floor on the South side (inocuppied space in the other house): 0,77±0,1

Windows type	Single-glazed windows, U = 5,68 W/(m².K) and g = 0,85.	Double-glazed windows, U = 2,7 W/(m².K) and g= 0,85 Single-glazed windows, U = 5,68 W/(m².K) and g = 0,85.
Infiltration rate under 4 Pa	I4 = 1,68 m³/h.m² **	I4 = 0,77 m³/h.m²
Inertia class	Heavy	Heavy
Mechanical ventilation	Only a simple extractor in the bathroom	An extractor in the laundry room.
Natural ventilation	Only windows opening, every morning for 10 min in winter and 30 minutes in summer.	Ventilation grids in the bathroom, toilets, and kitchen. Windows opening
occupants	A family of 2 adults and 2 teenagers.	A family of 2 adults and a young woman

*see table 1, calculation based on the thermal characteristic off the non-heated space.

**Unfortunately, the difference between infiltration from outside, infiltration from occupied and non-occupied appartment could only be assess by rough estimation.

For the heat transfer through the floor and walls between ajdacent heated spaces, the hypothesis is no transfer.

Elementary effects of sensitivity analysis

For each case, a reference model is built with the best estimation for each input data. Then a set of other simulations is performed. In each, one parameter is changed to the value at the edge of the uncertainty range. The simulation is made with the indoor air temperature fixed at the hour per hour measured value. The different schedules, for internal gains, blinds, natural ventilation,…, are interpreted as hour per hour datas. The figure 7 for the flat and the figure 9 for the house represent the relative impact of the elementary uncertainty on the annual heating needs. The couple of values in parenthesis for each parameter corresponds to an estimation for the precision of the data collection of this parameter. For instance, ±7% for the infiltration rate is the relative precision for the blower door test that has been used.

The behaviours of the two cases are close, except that the apartment has a higher ratio between glazed parts and opaque parts and then is more sensible to uncertainty on windows characteristics.The input data with the highest impact on the annual heating need for the apartment are in table 4.

In the house, the uncertainty on the U-value of the walls and the uncertainty on the measure of their surfaces lead to a maximum of respectedly 14% and 7% of variation on the annual heating need.

The behaviour of the occupants and the associated uncertainties are a topic of discussion in the scientific literature. Azar has published a study on the impact of occupancy parameters in energy simulation of office buildings (Azar, 2012). In some cases, the energy need result is multiply by 2. In our two cases, the energy need for the residential building is affected by the indoor temperature fixed in the simulation programs so by the temperature setpoint of the occupant. A rise of 30% of the internal gains gives an impact between 2 and 3% of annual heating need.

table 4: Parameters with the highest impact on the annual heating need for the flat

Rank	Input parameter	variation of the parameter	Relative impact on output
1	U opaque walls	15%	9%
2	Orientation	South instead of South-east	8,5%
3	Indoor temperature	0,7 °C	7,5%
4	Outdoor temperature	0,5°C	5%

Uncertainty analysis

Generally, uncertainty analysis include variables identified as the most influential in sensitivity analysis. In this study, the parameters have been assembled in 7 groups (Spitz, 2012) and the thermal model was approached by a simplified model:

- Enveloppe physical characteristics (factor 1)
- Internal gains (factor 2)
- Climatic conditions (factor 3)
- Indoor temperature (factor 4)
- Airchange / ventilation (factor 5)
- Solar gains (factor 6)
- Thermal Inertia (factor 7)

An analysis of the impact of the crossed uncertainties of these groups has been performed with factorial fractional design of experiment. The main hypothesis is the almost linearity of the model response at each factor. With 16 experiments for each case, the calculation of all the coefficients of the experimental design is possible. The response y of the model is approached by:

$$y = \mu + \sum_{i=1}^{7} a_i x_i + \sum_{i=1}^{6}\left(\sum_{j=i+1}^{7} a_{ij} x_i x_j\right) + \cdots + a_{1\ldots7} x_1 \ldots x_7$$

Where : $a_i$is a coefficient for the effect of the factor x_i between the average and the extrema; $a_{ij}$is a coefficient for the effect of the interaction of the factor x_i and $x_j$between the average and the extrema; µ is the average response of the system.

The factors, id est the level of the 7 groups of parameters, are centred and reduced to be in the interval [-1,+1]. To reduced the experimental design, the factor number 5 as been computed as the factor x_{123} , the factor number 6 as the factor x_{234} and the factor number 7 as the factor x_{124}. The table 5 presents the calculated coefficients for the two buildings.

The units for the response y is a yearly energy need for heating (kWh/(m².an)).

table 5: Coefficients of the meta-model

Coefficient	Case 1 :the flat	Case 2: the house
µ	1476	1575
a1	277	319
a2	69.4	80.2
a3	131	122
a4	114	62.3
a12	-4.59	-36.3
a13	14.4	0.52
a14	13.9	24.7
a23	2.56	3.22
a24	0.37	-6.36
a34	3.09	-25.2
a5	15.7	63.4
a7	-0.33	17.8
a134	4.15	38.9
a6	82	58.7
a1234	7.56	35

The average heating need of the house is 133 kWh/(m².year) and 128 kWh/(m².year) for the flat with the model.

The group with the most influence on the response of the model is the envelope group. It's in relation with the analysis on individual parameter and the high impact of the U-value of the opaque walls. No important interactions between the different groups has been identified.

The next step consists of a Monte Carlo analysis based on the meta model obtained with the factorial fractional design of experiment. In first approximation, an equidistibution is applied for the values of the level of the groups. 1000 runs of Monte Carlo are processed and the statistics on the 1000 corresponding responses are represented on the figure 8 for the apartment and on the figure 10 for the house.

The energy consumption of the house and the flat has been measured. There is also uncertainties to transform this information in energy need:

- Uncertainty on the energy sensor, due to gas dilatation and calorific power.
- Uncertainty on the partition between energy for hot water and energy for heating as the boiler is used for both.
- Uncertainty on the efficiency of the boiler.

The table 6 presents the results for the energy measurements part. The good values for the boilers efficiency are due to their recent replacement. The partition hot water / heating is obtained with the energy consumption in the non-heating period, in June and September to avoid holidays.

table 6: Energy measurments

	Flat	House
Energy consumption (kWh/(m².year))	128,2 ± 5%	217,6 ± 5%
Partition, hot water / heating	0,19 / 0,81 ± 0,07	0,11 / 0,89 ± 0,053
Efficiency of the boiler	0,87 ± 7%	0,89 ±7%
Heating need (kWh/(m².year))	90,7	174,1

Discussion and results analysis

The uncertainties in heat gains can be interpreted in two ways: in the magnitude of individual items and in the total number of item. For the internal gains of the occupants, there is the metabolic rate and the number of persons present at each time step in the building. As internal gains uncertainty could have a strong impact of the energy demand of a modern building (Brohus, 2009), it is not the case in traditional building with highest heating need. The group 2 in the experiment design, the one for internal gains, doesn't have a strong coefficient compared to other groups.

A second point is the strong impact of the uncertainties from the heat losses by heat transfer through the walls. There are the U-value and the surface of the wall. The figure 6 illustrates the complexity of the façade elements in the case of the apartment in Paris. Besides the classic uncertainties on thermal conductivity of the materials, there is the problem of the complex geometry and the variable thickness of the walls. In this case, a relative uncertainty of 16% for the U-value is difficult to improve. For the surface, with tools as rangefinders and old plans, it will be rare to have better than ±5%. Then the simulations on these sorts of buildings have to deal with this group of uncertainties and be ready to have an annual heating need or demand adjustable to as much as 15% depending on the hypothesis on the walls.

The second group with the highest impact coefficient is the number 3: weather data. The uncertainties used in this study depend on the quality of the weather station. Macdonald has worked with variation of ±0,2°C for the outdoor temperature, ±3% for the solar radiation and ±0,5 m/s for the wind speed (Macdonald, 2001). So it is possible to improve the precision on this group with better measurements.

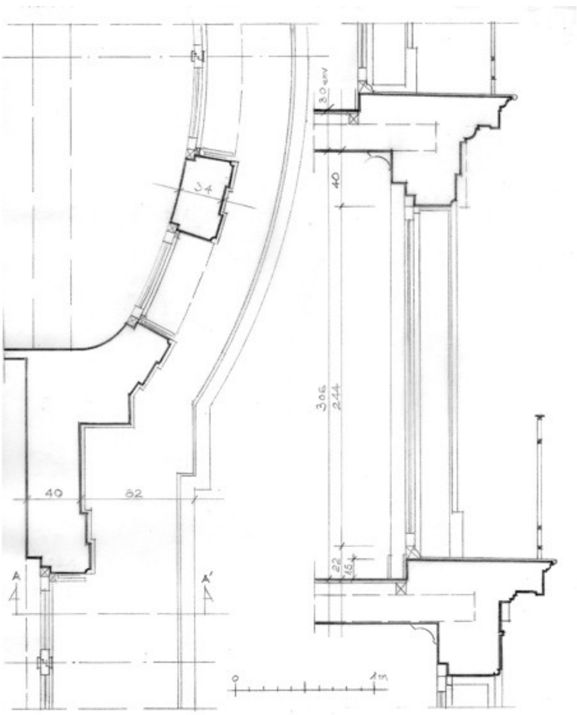

figure 6: Architectural elements on the façade of the apartment in Paris

After the Monte Carlo analysis, for both cases, the shape of the probalility for the annual heating need is close to a Gaussian around the average value. They are still relatively wide at the basis. The runs are equidistributed on the level of the seven groups so the results are rather pessimistic. The method will be perform again with other distributions. Spitz used normal and uniform distributions in (Spitz, 2012).

In the apartment case, the orientation has been tested as input data. The change from South-east to East and from South-east to South impact the yearly heating need of respectively +8,5% and -4%. Some simulation code allow the user to choose between North, South, East and West for the orientation. The limits are highlighed here.

The curves of the probability for the heating needs obtained with the model and the curves of the probability for the heating needs obtained with the measures overlap only on a small part. This result could have different meanings, the schedules of the stochastic phenomenon may not be precise enough even with the uncertainties considered. The boundary conditions, especially for the flat may have stonger impact than the one considered here. The conclusion about the validity of the model is not straightforward and need cautions.

Conclusion

On two study cases, the precision of the models concerning yearly energy simulation has been investigated. This paper point out the difficulties and the pitfall in announcing an energy consumption with a model of a traditional building. The construction process leads to uncertainty which can't be really reduced. Other uncertainties could be reduced by very precise measurements. The energy behaviour of the building obtained with simulation has in any way to be follow by the uncertainty on the energy consumption or heating/cooling need.

To compare simulation results and field energy measurements, uncertainties on the input data of the model have to be considered. According to this study, especially the characteristics of the walls, the weather data, the orientation and the indoor temperature command need the best estimation and cares for the uncertainties when dealing with traditional residential buildings. The comparison may pass by checking the probability of energy consumption with the model and with the measures.

ACKNOWLEDGEMENT

This work is part of a project funded by the French Ministry for ecology, energy and sustainable development.

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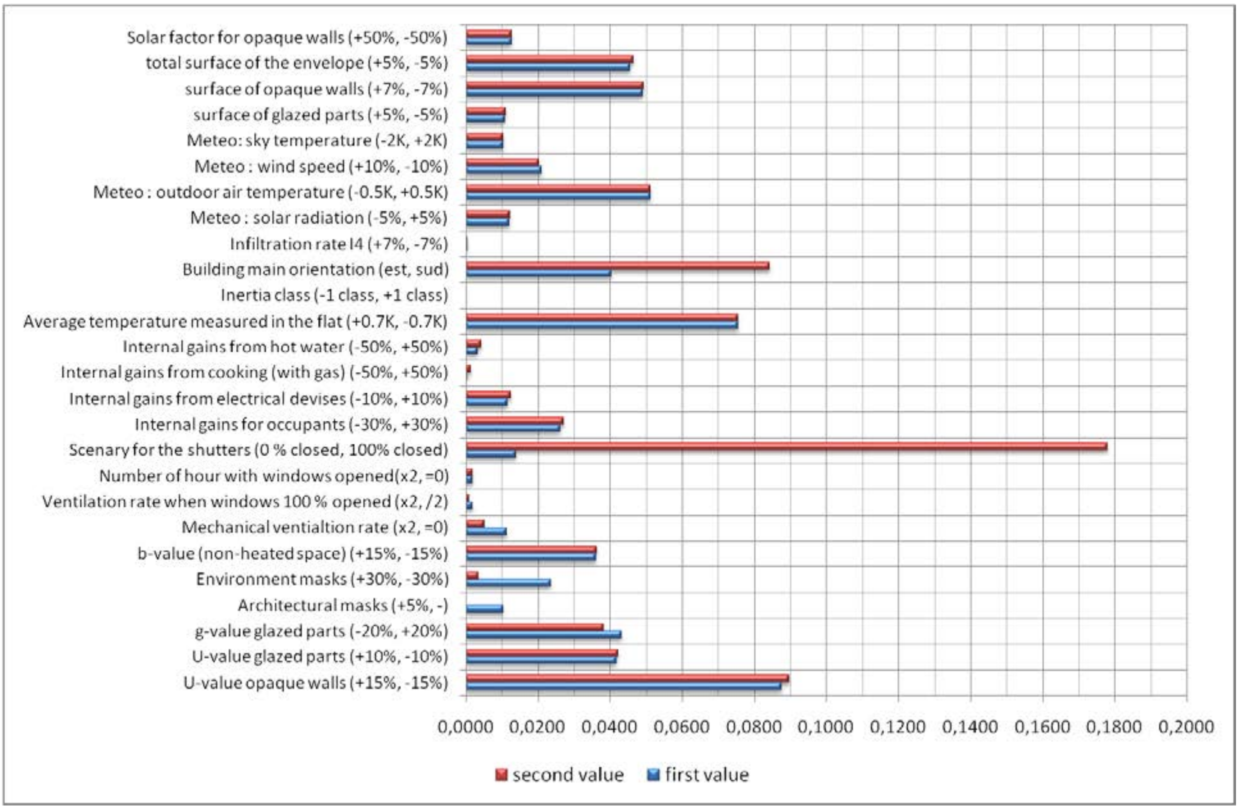

figure 7: Individual sensibiliy for the model of the flat

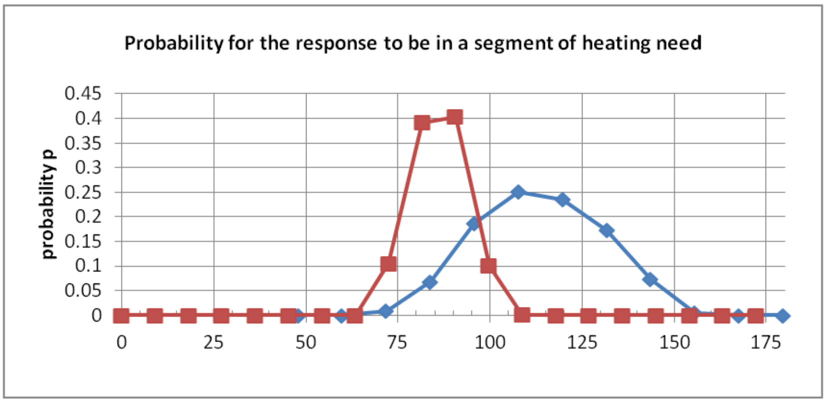

figure 8: Apartment in Paris: probability of heating need (kWh/(m².year)), red square for the measure and blue diamond for the model.

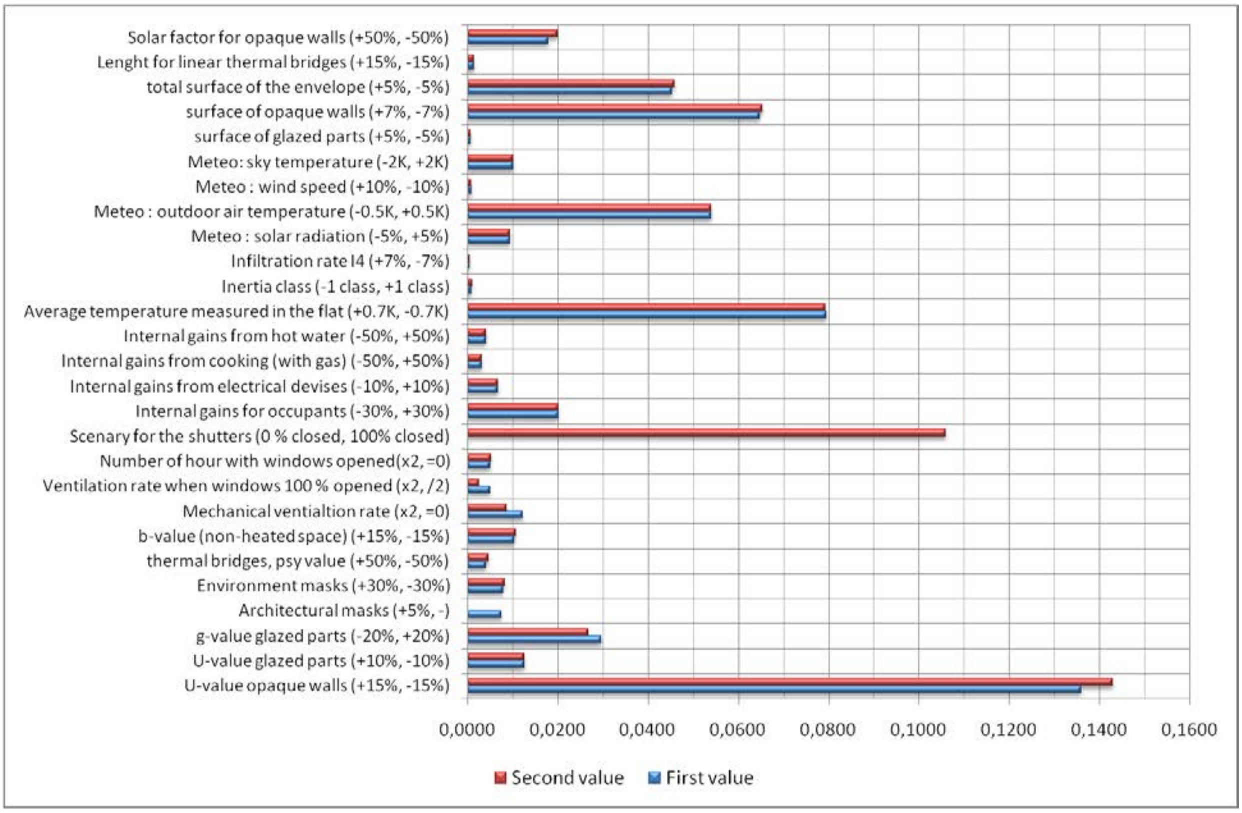

figure 9: Individual sensibility for the model of the house

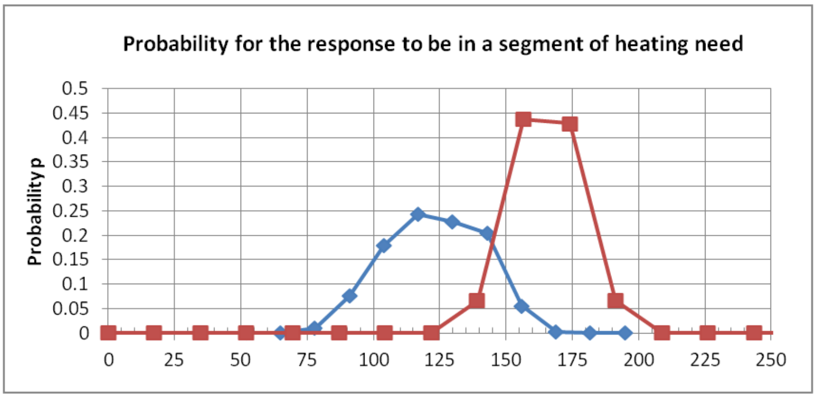

figure 10: House in Noisiel: probability of heating need (kWh/(m².year)), red square for the measure and blue diamond for the mode