Energy savings and costs of energy efficiency measures: a gap from policy to reality?

Marie-Hélène Laurent, Dominique Osso, Emmanuelle Cayre

Energy savings and costs of energy efficiency measures: a gap from policy to reality?

Marie-Hélène Laurent
EDF-R&D, ENERBAT Dpt
France
marie-helene.laurent@edf.fr

Dominique Osso
EDF-R&D, ENERBAT Dpt
France

Emmanuelle Cayre
EDF-R&D, ENERBAT Dpt
France

Keywords

energy savings, residential building, retrofitting cost, financial indicators

Abstract

Financial efficiency of retrofitting actions of dwelling stock is always difficult to evaluate. Even if retrofitting market is not driven by financial profitability, evaluation of any efficiency programme is necessary and relies primarily on energy saving calculations and costs assumptions. The main question is the accuracy of chosen assessments that depend to a large extent on available data and sources. In this paper, we discuss how arguable is an evaluation with 5 different methods of energy savings evaluation and 5 different sources of cost data. For each considered retrofitting action (3 for dwelling envelope, 2 for space heating system, and 1 for domestic hot water generation) 5 different financial indicators are calculated. Large number of results (900 data) allows discussion on data, sources and methods accuracy. Ranking of retrofitting actions and influence of chosen indicators are also discussed. Finally, the impact of energy saving evaluation methods and cost data on the cost and energy savings variability of retrofitting program is calculated.

Introduction

It is assumed that drastic energy savings in dwellings can't be achieved without strong retrofitting programmes. In new environmental laws, issued from the "Grenelle environment" round table to define the key points of French policy on ecological and sustainable development issues, the government targeted a reduction of 38% of energy consumption for the existing building stock by 2020. This means that around 400 000 dwellings have to be refurbished each year and the oldest ones have the highest priority (French National Assembly, 2008; Ministry of Ecology, 2008). Building envelope retrofitting is considered as a key action for retrofitting programs.

Otherwise, in agreement with the target of European Community, the French government is committing 23% of renewable in final energy consumption by 2020. This target will be partially achieved with technologies able to capture renewable energy at building scale (i.e. solar thermal, heat pump).

Moreover, part of these energy efficiency actions (retrofitting, renewable) are enclosed within the framework of the French White Certificates (FWC) mechanism (Ministry of Economics, 2006) and are countable as energy savings depending on the efficiency of the refurbishment.

Consequently, there are a lot of reasons to study efficiency of retrofitting actions and renewable technologies for buildings. It is assumed that most of these technologies are costly. However, more profitable actions are not the most common ones, and some actions are very popular, despite poor financial profitability. It is obvious that energy efficiency market for the residential sector is not solely driven by financial considerations. However, it is useful to study these actions from a financial point of view in order to adapt public policies and commercial offers or to value the energy efficiency (Baudry, 2008).

Assessment of cost effectiveness of main energy efficiency actions for a large retrofitting of building stock is basic to understand the best policy for householders to reduce their energy consumption. It is also necessary to give some indication on the fulfilment of the 2020 objective and the cost of such a large refurbishment program. Finally, it is important to have a good view of where financial incentive, in the form of soft loan and tax rebate, will be given to private owner by public funds.

Unfortunately, few studies deal both with cost and energy savings. Therefore, we have to use data from different sources bringing additional uncertainty besides these related to saving assessment (Baudry, 2007). Moreover, the different studies never provide similar data as they use different assumptions or assessments and are difficult to compare. In this paper, the only common source for costs and energy saving we have found is from the French Energy Performance Certificate (EPC), and results demonstrate that they are not the most accurate.

In this paper, we discuss how uncertain an evaluation of some current energy efficiency actions is with the figures used.

Methodology and data

This paper's case study is one of the main targets of existing buildings needed to be retrofitted and has been chosen so that we can compare different existing methods of energy saving calculation per retrofitting actions. The focus is on detached houses built between 1948 and 1975 (i.e. before any thermal regulation) and without retrofitting, fuelled with oil and located in the north of France. Within the main housing stock, oil-fuelled detached houses built between 1948 and 1975 there are 1,152 million and they represent an assessed consumption of about 24 TWh for space heating (CEREN, 2008-a); the total French building stock includes 26.19 million of dwellings (INSEE, 2008).

The study covers three actions related to envelope retrofitting:

- single glazing windows replaced by low emitting double glazing filled with argon,
- virgin loft insulation,
- walls internal thermal insulation.

The study also covers two actions on space heating systems and one concerning domestic hot water production:

- condensing gas boiler (CD) (space heating only),
- high temperature and efficiency heat pump (HP) (space heating only),
- solar heating panels for domestic hot water (SDHW) production.

The gas boiler considered is a condensing gas boiler with global annual efficiency of 0.9 (all included). The heat pump is an air/water "high temperature" pump being able to deliver hot water with sufficient high temperature which is necessary because of small emitter surface used with old oil boiler. Old French space heating radiators are quite small and need a high level of temperature in the circulating loop. The chosen heat pump covers all space heating needed by pure thermodynamic cycle. There is no additional direct electric heating. Global seasonal COP of this HP is not chosen very high and is about 2.5.

The domestic hot water system is a solar one with an added electrical resistance. We have also made some calculations with a combination of existing gas boiler and solar panels, but results were negative (more energy consumption after adding solar panels). Heat losses from necessary hot water storage (that was not in the previous system because boiler was supplying sanitary hot water without a storage vessel) were more important than the savings due to the solar energy. Consequently, the chosen system is a combination of solar panels and new electric hot water generator with storage vessel.

In order to compare different evaluations of these refurbishment actions, we have chosen to mix several data and calculation methods, for energy saving and cost per retrofitting action to provide various financial indicators. The methodologies used for energy savings estimation are notably based on thermal regulation, energy performance certificate or FWC.

METHODS FOR ESTIMATING ENERGY SAVINGS

We have chosen the methodologies described below because they are generally used for estimation or calculation but with different purposes. With the calculation methods giving energy consumption and not directly energy savings, we have used a "before/after" refurbishment approach to assess the savings.

Field studies

To estimate the energy savings from field study we used data from Economic Research and Study Centre on Energy (CEREN, 2008-a, CEREN, 2008-b) which provide figures based on a time series from 1997 to 2006 of 3627 houses with an oil boiler, built before 1975. This database allows assessing real energy savings after retrofitting actions from the energy bills of the households and enquiries. The statistical methodology applied relies on before/after and with/without comparisons. These data include all effects as rebound or discrepancy ones.

Enhanced engineering estimate

Enhanced Engineering Estimates (EEE) of the energy savings (ΔE) are calculated on the basis of thermal losses decrease including a rebound effect (RE) and a discrepancy effect (DE) (bad workmanship) of the retrofitting building envelope following equation 1:

$$\Delta E = \left[\frac{(U_i - U_f) * HDD * 24 * 10^{-3} * I}{\eta} \right] * RE * DE \qquad (1)$$

with:

- U_i, U_f: initial (i) and final (f) thermal transmittance of insulation (W/m². °C).
- HDD: heating degree days (°C) (HDD=2424 C).
- η: efficiency of the heating system.
- I: intermittency factor (I=0.72) (see appendix A).
- RE: rebound effect coefficient (remaining energy saving: a rebound effect of 0.3 give RE=0.7).
- DE: discrepancy coefficient.

For space heating system, EEE energy saving calculation is simply based on the initial consumption C_i and the ratio of initial and final efficiencies, η_i and η_f, corrected by rebound and discrepancy effects:

$$\Delta E = Ci * \left(1 - \frac{\eta_i}{\eta_f}\right) * RE * DE \qquad (2)$$

Table 1: Characteristics of studied dwelling (surface: 115.6 m²) before and after retrofitting.

	Characteristic	Efficiency before retrofit	Efficiency after retrofit
Wall	Area: 142 m²	Uwall: 2.5 W/m².K	Uwall: 0.38 W/m².K
Roof	Area: 59.4 m²	Uroof: 4.0 W/m².K	Uroof: 0.18 W/m².K
Windows	Area: 12.88 m²	Uwindow : 4.2 W/m².K	Uwindow :1.55 W/m².K
Boiler	Boiler power: 24 kW	Boiler efficiency: 0.65	Boiler efficiency: 0.9
Heat pump	Heat pump power:13 kW	–	Coefficient Of Performance: 3 HP Seasonal Heating Performance Factor:2.5
Solar DHW (**)	Solar panel surface: 6 m²	–	fraction of executive energy covered with solar energy: 0.7

Climate zone H1a as defined in French thermal regulation (RT2005). U: thermal transmittance. (**) in the lack of energy efficiency data, default values of the calculation methods were used especially in the conventional one or for the field study.

Table 2 : Data used for estimating energy savings in the French White Certificate scheme.

	Thermal transmittance (W/m².°C)			**SDHW**	**Space heating efficiency**		
	Uwall	Uroof	Uwindow	Energy provided by solar panel	Oil boiler	Heat pump	Condensing gas boiler
initial	3.3	2.0	4.5	-	0.6	-	-
retrofitted	0.37	0.18	2.0	250 kWh/m²	-	3	40% of initial consumption

RE and DE of equation (1) and (2) are introduced to reflect respectively the behaviour of the household and the technical problems that can occur during refurbishment and reduce potential savings. RE could be described as the increase of thermal comfort after enhancement of energy efficiency. RE was intensively studied (see e.g. Greening, 2005; Geller, 2005) but figures of RE for space heating never lead to a consensus. In this paper, RE is chosen with a value of 0.7 according to previous studies. For the space heating systems and SDHW (Solar Domestic Hot Water) the values are slightly different (DE=0.9 in both cases and RE=0.9 only for SDHW).

DE was poorly studied due to the difficulty of its assessment even this effect is admitted. The value of the discrepancy effect (DE=0.8) is based on research conducted in UK during cavity wall insulation campaigns (Hong, 2006).

Method for estimating energy savings in the French White Certificate scheme

FWC energy savings evaluation is based on equation (1)(ATEE, 2005) without taking into account rebound effect or any discrepancy of the refurbishment (i.e. RE=1, DE=1) and represent theoretical savings. FWC energy saving are fixed, and values of the different assumptions are presented in the Table 2.

Method for estimating energy savings in the Energy Performance Certificate scheme

Calculation method of the French Energy Performance Certificate (EPC), called 3CL-DPE, is a simplified annual method, based on French 1988 thermal regulation (RT1988)(Ministry of Employment, 2006-a) which could be applied to our case study. Quantization was made with DPEWIN® software used for the calculation of EPC (Perrenoud, 2007-a).

Method for estimating energy savings in French thermal regulation

The calculation method of the last French thermal regulation (RT2005), called Th-C-E 2005 and developed by CSTB (Scientific and technical centre for building), is based on dynamic simulation in step of hourly time (Ministry of Employment (2006-b). The calculations were made with U21W05® software used for thermal regulation 2005 studies for new buildings (Perrenoud, 2007-b).

COSTS

Among various data we have to collect in order to evaluate efficiency of energy retrofitting actions, costs are probably the most delicate and difficult to get properly. Despite the fact that these data sources are not so common, values of gathered data cover a wide range, and make the choice of a sole value supposed to be representative of the market difficult. As a general rule, cost could be divided in four parts:

1. Principal cost for the equipment (e.g. a condensing boiler, area of insulating material…),
2. Secondary costs covering additional equipments (pipe, energy management device, water storage vessel…),
3. Labour cost (i.e. cost concerning the implementation of equipments),
4. Hidden cost or additional cost covering miscellaneous expenses (e.g. cleaning, waste disposal, scaffolding, painting...).

However, it is not always possible to deal with hidden costs or secondary costs correctly. As far as possible, for each kind of cost data used in this study, we precise the kind of included costs.

In our study, costs are understood as net full costs including at least principal equipments costs and labour costs. VAT and various possible financial incentives as grants or tax rebates are not included, so costs are ex-VAT. We distinguish four types of cost even if the difference is not always easy to determine:

- Normative Costs (NCs) including only principal and labour costs.
- Basic Costs (BCs) including NCs and secondary costs.

- Full Costs (FCs) including BCs and hidden costs.
- Effective Costs (ECs) including FCs as well as tax rebate, soft loans…

Five different sources of costs are used:

- Costs coming from the French EPC for dwellings (Ministry of Employment, 2007) Cost data are included in the technical guidance edited by the French government for evaluators training and could be considered as normative cost (NCs).
- Database "Batiprix" for French market edited by Groupe Moniteur (Batiprix, 2008). These data are well known and considered as basic costs (BCs) by building industry and professionals.
- Costs from case studies edited by French national agency for dwelling (ANAH, 2007). ANAH is well implicated in operations of urban renewal and upgrading of large dwelling refurbishment campaigns. However, this booklet doesn't give data relying on real operations but cases are studied by UNTEC (National Union of Building Industry Economists and Coordinators). They can be considered as Basic costs (BCs).
- Cost data from French survey of energy efficiency market from National Agency of Energy and Energy Management (ADEME, 2008). These public data can be considered as full costs (FCs).
- Costs coming from analysis of invoices gathered by EDF-R&D from different field studies. Since hidden costs are included and represent around 30% of total cost, these data are full costs (FCs).

FINANCIAL INDICATORS

Even if it is well known that energy efficiency market for the residential sector is not only driven by financial considerations, it is useful to estimate the financial indicators in order to adapt public policies and commercial offers. Table 5 summarizes the 7 financial indicators calculated in this paper and the used assumption.

Every financial calculation is made with the following assumptions: constant energy price and energy savings over time, lifetime of 16 years for thermal systems and 35 years for insulation, in accordance with FWC assumptions (Ministry of Economics, 2006) even if other value could be used elsewhere (CEN, 2007). Every energy price exclude VAT, but include standing charge (Table 4).

Choice of discount rate is important for financial indicators. It is assumed that households have a very high level of discount rate of at least 20% (Ansar, 2008; Train, 1985; Jaffe, 1994). But, in order to comply with FWC, a low discount rate of 4% is chosen. This very low value, which is representative of a public investment with a welfare goal, gives advantage to retrofitting actions with long lifetime.

However, financial calculations with a time as short as 10 years, as done in this paper to complete financial indicators over lifetime, are a way to report high level of discounting rates and short pay back times assumed with the residential market.

Finally, the estimated energy saving (5 values) and the different costs (5 data) were used to draw a square matrix of 25 different results per financial indicators on the basis of two values (saving, cost). Finally, descriptive statistics were conduct on these results (average [μ i], mean [$\tilde{x}_i$], standard deviation [σ_i], minimum and maximum values).

Cost of Saved Energy

Cost of Saved Energy (CSE) is based on normative calculation coming from FWC net saved energy (Ministry of Economic, 2006) and calculated as the cost of one specific action (C_{inv}) divided by the annual energy savings (ΔE) cumulated over time (n=10y or lifetime) and discounted (a):

$$CSE = \frac{C_{inv}}{\Delta E * \sum_{p=1}^{n} \frac{1}{(1+a)^p}} = \frac{C_{inv}}{\Delta E * \left[1 + \frac{1}{a}\left(1 - \frac{1}{(1+a)^{n-1}}\right)\right]} \quad (3)$$

CSE allows building an indicator which is independent from future evolution of energy prices. It is useful when it is not easy to make assumptions about future energy costs, which is quite representative of the period. It represents the cost of avoided MWh on a pure investment cost point of view. It is not a classic financial indicator because of missing running costs in the formulae. This kind of calculation is also used in UK EEC (Energy Efficiency Commitment) programs (Lees, 2008).

Break Even Time

Break Even Time (BET), also called Payback Time, which is the time (year) to recover an initial investment due to future economies. BET is calculated as the ratio of initial investment (C_{inv}) and the annual financial gain of energy saving calculated as the difference between initial consumption (C_i) and final consumption (C_f) and the corresponding energy price of initial (P_i) and final (P_f) energy:

$$BET = \frac{C_{inv}}{(Ci * Pi - Cf * Pf)} \quad (4)$$

Net Present Value

Net Present Value (NPV) is the total present value (Euro) of a time series (n) of discounted (a) net cash flows (Rt_i):

$$NPV = \sum_{i=1}^{n} \frac{Rt_i}{(1+a)^i} \quad (5)$$

NPV is able to compare different investments projects on basis of volume of expected profit. As NPV gives the level of magnitude of the profit indicator, it avoids calculation of global annual cost. Ranking of retrofitting actions should be the same with NPV calculated without discounting and global annual cost. That is the reason why we have decided not to consider global cost.

Internal Rate of Return

Internal Rate of Return (IRR) is the discount rate (a) that makes the NPV (equation 5) of the investment's income stream total to zero at the time (n) chosen for calculation. IRR is calculated over 10 years and lifespan. IRR is an indication of financial profitability of investment. It allows comparisons with other kinds of investments (e.g. financial products of bank). It doesn't

Table 3: Different data sources.

Cost source	Data availability	Data status	Type of cost	Hidden costs
Batiprix	Commercial	Estimation	BCs	No
EPC	Public	Estimation	NCs	No
ANAH	Public	Estimation	BCs	No
ADEME	Public	Case study	FCs	probably
EDF	Unavailable	Case study	FCs	Yes

Table 4: Prices of energy (DGEC, 2008). Oil price is the average over year 2008.

Energy	Euro inclusive of all tax per MWh (low caloric power)	Euro exclusive of VAT per MWh (low caloric power)
gas	59	50
electricity	120	102
oil	75	64

Table 5: Financial indicators characteristics.

Financial indicator	Unit	Time serie (n)	Discount rate
CSEn	Euro ex-VAT/MWhcum$_n$	n=10, 16 or 35 years	4%
BET	years	-	-
IRRn	%	n=10, 16 or 35 years	4%
NPVn	Euro ex-VAT	n=10, 16 or 35 years	4%

MWhcum$_n$ = MWh cumulated and discounted over n years. CSEn: cost of saved energy over n years.
BET: Break Even Time, IRRn: Internal rate of return over n years, NPVn: Net Present Value over n years.

give idea of level of future profits, but rather efficiency of the investment.

Results

ENERGY SAVINGS

A large uncertainty is linked with energy savings assessment, depending on the methodology considered as the dispersion is high (Table 6). Excepted for SDHW, it is remarkable that the ratio between maximum and minimum evaluated savings is never under 3.9. For envelope and space heating actions, the different methodologies could be divided in three groups:

- EPC and RT2005 methods give estimations in the highest level of ranking. EPC always gives the highest evaluation of energy savings.
- Field study and EEE calculations, most of the time, give the smallest estimations.
- FWC method is always in the mid ranking.

It is not surprising that normative methodologies (assuming that people have a "normative" behaviour regarding space heating management) give larger estimations than methods closer to real conditions. It is interesting to notice that the FWC approach is closer to "reality" than normative methods even if calculations are based on fixed estimations.

EEE and FWC estimations are close, due to that EEE methods using a combination of several corrective factors (I*RE*DE=0.4) close to the value of the unique intermittency factor used in FWC approach (I=0.5). This unique factor seems not only to represent intermittency (i.e. energy management) but also a global corrective factor including also free supply energy (internal load, solar flow).

SDWH leads to the opposite conclusion than for envelope and space heating actions. Normative methods give the lowest energy saving estimation, and the lowest ratio between maximum and minimum savings is the lowest one (less than 2).

COSTS

Dispersion values for cost is smaller than energy saving assessment. The ratio between maximum and minimum cost values never exceeds 3.5. Ranking of costs is less homogeneous than the energy saving evaluation one. Unlike energy savings, the SDHW case study doesn't change main conclusions:

- EPC and Batiprix give the smallest costs as they are NCs or BCs,
- Data from EDF and ADEME give largest costs since they are FCs,
- ANAH evaluations are in the mid range.

However, costs ranking (Table 8) doesn't allow determining type of cost (from NCs to FCs). EPC combines highest estimations for energy savings and the smallest costs should obviously lead to the best financial indicators as we will see below.

FINANCIAL INDICATORS

Each choice of energy savings figures can have 5 different values regarding methodology (Table 6) and it is the same for cost choices regarding their sources (Table 7). Consequently, for one financial indicator, we have 25 possible combinations. 6 financial indicators are calculated, so analysis can be conducted on 150 results per retrofitting action. Three types of analysis can be done with the different financial indicators:

- Statistical analysis to show how arguable the efficiency is of a refurbishment action depending on the assumption used.

Table 6: Energy savings of studied refurbishment actions according to different methodologies.

Method	*Type of evaluation*	Windows (kWh/dw)	Virgin lofts (kWh/dw)	Walls (kWh/dw)	Gas condensing boiler (kWh/dw)	Heat pump (kWh/dw)	Solar heating for DHW (kWh/dw)
RT 2005	*specific*	2831	13234	18762	6641	39967	1091
EPC	*specific*	8770	14566	20556	16772	54152	1458
EEE	*specifc*	1329	4210	9070	3114	8520	1970
FWC	*general*	1578	5297	20390	11099	13887	1500
Field Study	*general*	636	1479	5332	4749	8924	– (*)
Average	–	3029	7757	14822	8475	25090	1504
Max/Min	–	13.8	9.8	3.9	5.4	6.4	1.8

(*) no available data from our field study for SDHW.

Table 7: Costs of retrofitting actions according to data sources.

Cost sources	Windows (Euro ex-VAT/dw)	Virgin lofts (Euro ex-VAT/dw)	Walls (Euro ex-VAT/dw)	Gas condensing boiler (Euro ex-VAT/dw)	Heat pump (euro ex-VAT/dw) (*)	Solar heating for DHW (Euro ex-VAT/dw)
ADEME	8393	1333	2791	8210	13000	6864
ANAH	5173	1772	6289	8810	3800	12771
Batiprix	7213	772	4971	5858	10127	6276
EDF	7419	2257	5397	6710	13154	8502
EPC	5152	1782	4971	5310	9000	5100
Average	6670	1583	4884	6980	9816	7903
Max/Min	1.6	2.9	2.3	1.7	3.5	2.5

(*) due to lack of figure from EPC guideline data source is guide PAC (Target Media, 2008). Costs not are not including financial incentives.

Table 8: Ranking of retrofitting actions according to financial indicators.

	Windows (Euro ex-VAT/dw)	Virgin lofts (Euro ex-VAT/dw)	Walls (Euro ex-VAT/dw)	Gas condensing boiler (Euro ex-VAT/dw)	Heat pump (Euro ex-VAT/dw) (*)	Solar heating for DHW (Euro ex-VAT/dw)
CSE_{10} ranking	5	1	2	3	4	6
NPV_n ranking	5	2	1	3	4	6
Average ranking	**5.0**	**1.3**	**1.7**	**3.1**	**3.9**	**6.0**

Average ranking is based on all financial indicators calculated.

- Comparison of financial indicators by themselves to determine the most useful,
- Comparative study to rank the different retrofitting actions,

We must keep in mind, regarding the presented financial results, that they are calculated without taking into account possible financial incentive like tax-rebate and are of different kinds (FCs, BCs or NCs).

Statistical analysis

Figures below present results for 25 combinations (saving, cost) for the five financial indicators applied. On the x-axe, the numbers refer to various estimated savings and coloured bar charts represent different costs. In these figures, chosen examples are representative of whole results.

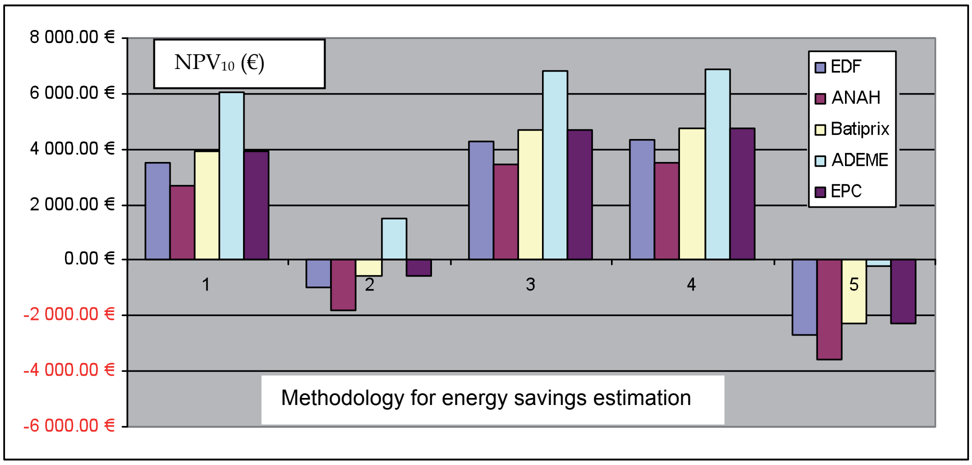
Generally speaking, calculated financial indicators (see appendix B for the whole figures) present a wide dispersion with a standard deviation (σ) in the same order as the median value ($\tilde{x}$) or average (μ). For example, the $\tilde{x}_{NPV_{10}}$ for wall insulation is about 3500 Euro with a $\sigma_{NPV_{10}}$ = 3200 Euro. We notice that the largest variations are mainly due to energy saving assessments. This is easily understandable because the largest ratio between maximum and minimum values is coming from energy saving figures. Conformity with energy savings estimations, the most positive financial indicators are with EPC savings followed by RT2005. At the opposite end, the field test leads to the most negative financial indicators.

We notice that for each retrofitting action, there are always at least a few values (saving, cost) giving negative profitability for NPV_{10} or IRR_{10}. This emphasizes the impact of the duration chosen for financial calculation. Obviously, indicators calculated on the lifetime are more favourable but negative values always exist.

Depending on the data (saving, cost) used, one action is found profitable or not. For example, concerning condensing boiler (Figure 2), the minimum IRR_{35} is about -7.6% and the maximum is 11.3% while $\tilde{x}_{IRR_{35}}$ is -2.1% highlighting a large standard deviation.

Even with the same methodology for the savings estimation, the profitability could be questionable. For example, concerning the windows replacement with savings issued from RT2005 calculation, the range of IRR_{35} is from -0.94% to 1.44%.

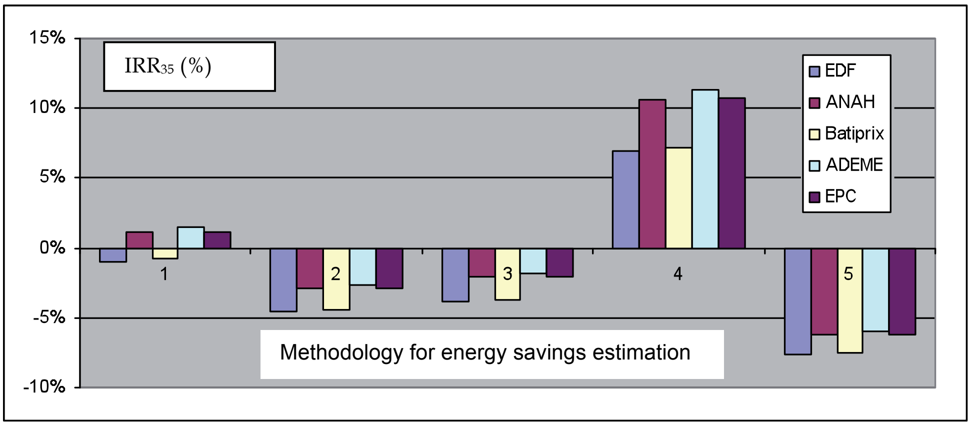
Finally, such statistical analysis points out a debatable data source for a specific retrofitting action. In the heat pump case, Figure **3** underlines a standard deviation ($\sigma_{IRR_{16}}$ = 21.7%)



($\mu_{NPV_{10}}$ =2192 Euro, $\tilde{x}_{NPV_{10}}$ = 3505 Euro, $\sigma_{NPV_{10}}$ = 3223 Euro).

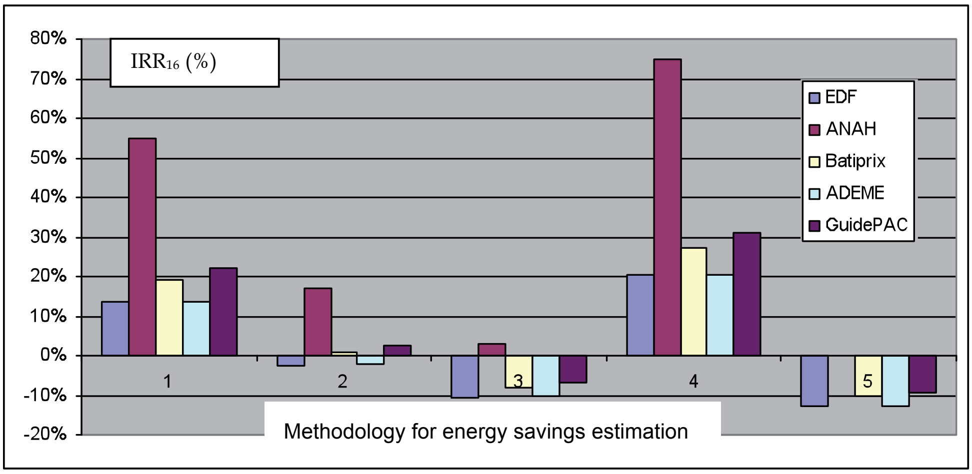
Methodology used: (1) RT2005, (2) EEE, (3) FWC, (4) EPC, (5) Field test.

Figure 1: NPV_{10} values for internal walls insulation in accordance to cost sources (coloured bars) and savings methodologies (x-axis).



(μ_{IRR35} = -0.6%, $\tilde{x}_{IRR_{35}}$ = -2.1%, σ_{IRR35} = 5.7%). Methodology used: (1) RT2005, (2) EEE, (3) FWC, (4) EPC, (5) Field test.

Figure 2: IRR_{35} for windows insulation in accordance to cost sources (coloured bars) and savings methodologies (x-axis).



($\mu_{IRR_{16}}$ = 9.4%, $\tilde{x}_{IRR_{16}}$ = 2.4%, $\sigma_{IRR_{16}}$ = 21.7%). Methodology used: (1) RT2005, (2) EEE, (3) FWC, (4) EPC, (5) Field test.

Figure 3: IRR_{16} for heat pump in accordance to cost sources (coloured bars) and savings methodologies (x-axis).

which is nine times the mean value ($\tilde{x}_{IRR_{16}}$ = 2.4%) due to the ANAH cost value apparently too low. If this value is eliminated, the standard deviation is reduced ($\sigma_{IRR_{16}}$ = 15.3%) with $\tilde{x}_{IRR_{16}}$ = 0.8%.

Comparison of financial indicators

In order to compare financial indicators' results, we have chosen median figures as representative of indicator value. Despite a large dispersion of financial indicators' results lead to the same tendency concerning efficiency or profitability.

Because CSE is the only indicator that doesn't rely on assumption for future energy prices, it could be chosen as the indicator from a purely energy efficiency point of view. The CSE, for example for loft ($\tilde{x}_{CSE_{35}}$=13 Euro/MWhcum$_n$) and roof insulation ($\tilde{x}_{CSE_{35}}$=16 Euro/MWhcum$_n$) leads to the same financial profitability (respectively $\tilde{x}_{IRR_{35}}$ = 26% and $\tilde{x}_{IRR_{35}}$ = 21% for loft and roof insulation).

The particular case of fuel switching (i.e. from oil to gas or electricity) is different because the financial indicators don't lead to the same tendency. For example, the $\tilde{x}_{CSE_{16}}$ for heat pumps is 36.8 Euro/MWhcum$_n$ and the $\tilde{x}_{CSE_{16}}$ for condensing boilers is 83.4 Euro/MWhcum$_n$, and IRR are respectively $\tilde{x}_{IRR_{16}}$ = 10% and $\tilde{x}_{IRR_{16}}$ = 2% for condensing boiler and heat pump.

Ranking of refurbishment actions

In spite of a high dispersion of the financial results, we could lead a merit order analysis on the basis of median values (μ) and try to draw concluding remarks remaining exclusively dedicated to our case study. From the financial point of view, the energy efficiency actions could be divided in 3 groups taking into account that the ranking is without financial incentives:

- Profitable actions in less than 10 years including virgin loft and walls insulation,
- Profitable actions before end of lifetime including condensing boiler and heat pump.
- No financial viable actions before end of lifespan including windows replacement and SDHW.

By combining ranks from each financial indicator (Table 8) the average ranking is:

1. Virgin lofts.
2. Walls.
3. Condensing boiler.
4. Heat pump.
5. Windows.
6. SDHW.

The most profitable action is the virgin loft insulation with a μ_{BET} about 4 years and an $\mu_{IRR_{10}}$ around 21%.

Cost and savings of a retrofitting programme

As previously presented, our study could help to assess the cost of a large retrofitting programme as foreseen by the French government by 2020. Refurbishment of whole oiled-fuelled detached houses built between 1948 and 1975 (our case study) could be described as follows on the basis of the remaining works to do (according to data provided by national statistics (INSEE, 2002)):

- Virgin loft insulation: 50% of the segment dwelling stock (i.e. 0.576 millions to be retrofitted).
- Wall insulation: 60% (i.e. 0.691 millions).
- Window replacement: 50% (i.e. 0.576 millions).
- Heat space system replacement:
  - Gas condensing boiler: 60% ((i.e. 0.691 millions).
  - Heat pump: 40% (i.e. 0.460 millions).

We must notice that to reduce uncertainty estimation, we didn't use data from EPC. Our hypotheses lead to an estimated total investment with a minimal amount of 12.6 GEuro and a maximal of 25.5 GEuro with an average of 19.3 GEuros calculated as the sum for each refurbishment actions of number of dwellings to be retrofitted multiplied by cost of action.

We must keep in mind that the initial consumption for space heating of the building stock of our case study is 24 TWh. Concerning energy savings a rough assessment, as we cannot add direct savings from envelope with these links to heating system replacement, is the following:

- Insulation savings: assessment from 4.9 TWh to 23.3 TWh with an average of 16.4 TWh.
- Heating space savings: assessment from 12.1 TWh to 49.4 TWh with an average of 33.8 TWh.

The dispersion of these figures emphasises how it is difficult to assess an energy efficiency policy as well as for cost than for energy savings.

Conclusion

The choice of energy savings methodologies has a strong impact on evaluated profitability of studied retrofitting actions. So, an exclusive methodology isn't enough to evaluate an energy efficiency program. Moreover, as the methods based on thermal calculation are overestimating energy savings compared with field test estimation, it is necessary to conduct more field studies in order to enhance the reliability of assessed savings. EPC (and to a lower extent RT2005) in particular leads to optimistic financial figures.

On the contrary, conditionally to calculate with a lifetime duration instead of a short period (e.g. 10 years), only (and any) one of tested financial indicators seems sufficient to appreciate the relevance of an energy efficiency programme.

Concerning refurbishment actions our concluding remark can only be applied to our case study (1948-1975 built oil-fuelled houses). However, we could say that despite the small number of thermal walls and virgin lofts insulation compared to window replacements, financial results are always positive for these two first kinds of actions. On the contrary, window replacements are widespread even if the profitability is poor with all tested financial indicators. These results confirm that financial profitability is not necessary and not sufficient to assure market success of retrofitting actions. The keys for success have to be found in successful examples as windows replacements:

strong and organised existing commercial offers, adapted products for retrofitting because of low interference, investment but with slightly less importance (partly due to the possibility to process step by step), and last, but not least, positive side effects as acoustic and thermal comfort enhancement as well as aesthetic considerations. In other words, grants or rebates will not make these actions more attractive on a financial point of view and are probably not sufficient to promote virgin loft and wall insulation, but they can facilitate decision-making.

Solar domestic hot water is a different case. Profitability is even lower than window replacements, and investment is high, but it represents an emerging market. Commercial offers are more and more visible, implementation of recent solar panels is quite well adapted to retrofitting constraints (and visible from neighbourhood), and, more importantly, solar energy is a renewable one. There is a bonus for using renewable energy; people eager to install solar panels are likely to accept lack of profitability and high investment (especially since important public grants minimize it) in return for environmental consideration.

Despite high energy efficiency, space heating system replacement gives average profitability which is never the worst or the best one. The quality of financial indicators is very sensitive to chosen time for calculation. Replacement is unavoidable (life span of boilers and heat pumps are relatively shorter in comparison to the envelope) and linked investment is high. In that case, financial helps are really useful, especially for more efficient equipments. Calculations with both average technology (market representative) and best available technology (with over-cost and over-energy savings analysis) would be valuable in order to have a better understanding of profitability on these kinds of retrofitting actions.

Beyond space heating equipments, these calculations have to be completed for all kinds of evaluated retrofitting actions with costs including various grants and loans and with comparison between cost and energy efficiency of standard equipments and best available technology.

In order to appreciate a wider range of possible actions for a complete retrofitting campaign, different approaches have to be investigated.

Glossary

BCs: Basic Costs
BET: Break Event Time
CD: Condensing Boiler
COP: Coefficient Of Performance
CSE: Cost of Saved Energy
DE: Discrepancy Effect
ECs: Effective Costs
EEE: Enhanced Engineering Estimate
EPC: Energy performance Certificate
FCs: Full Costs
FWC: French White Certificate
HDD: Heating Degree Days
HP: Heat Pump
I: Intermittency
IRR: Internal Rate Ratio
NCs: Normative Costs
NPV: Net Present Value
RE: Rebound Effect
RT1988, RT2005: Thermal Regulation of years 1998, 2005
SDHW: Solar Domestic Hot Water
U: Thermal Transmittance
VAT: Value Added Tax

References

ADEME (2008), Permanent monitoring of housing energy efficiency enhancement [*Observatoire permanent de l'amélioration énergétique du logement – OPEN*] (2008) 147p

ANAH (2007), Evaluation guideline for retrofitting and rehabilitation of flat and houses [*Guide d'évaluation des travaux – Réhabilitation – Appartement et maisons individuelles*] (2007) 70p

Ansar J. et al. (2008), The experience curve, option value, and the energy; Energy Policy (2008) doi : 10.1016/j.empl.2008.10.037, to be published

ATEE (2005) Technical Association on Energy and Environment, Energy saving certificate, calculation sheet, *insulation of walls,* BR93, rev. 7, December 2005

Batiprix (2008), Volume 1 gros œuvre – Second œuvre – 26th Edition – Edited by Groupe Moniteur

Baudry P. (2008), Energy efficiency and integrated planning of resources, learning from the Californian model [*Efficacité énergétique et planification intégrée des resources, les enseignements du modèle californien*], Revue de l'Energie, n°585 (2008) 1-7

Baudry P. et al. (2007), Uncertainties in the evaluation of energy savings potential, ECEEE 2007 summer Study – Saving Energy – Just Do It!, June 2007, La Colle sur Loup – France, 583-588

CEN (2007), CEN/CENELEC, Lifetimes of Energy Efficiency Calculations, CEN Work Shop CWA27 (2007)

CEREN (2008-a), Economic Research and Study Centre on Energy –, Monitoring of the building stock and energy consumptions [*Suivi du parc et des consummations*], ref. 8102 (2008) 418p

CEREN (2008-b),Economic Research and Study Centre on Energy – CEREN, Insulation opf building shield and space heating retrofitting effect on energy consumption for the dwellings built before 1975 [*effets de l'isolation du bâti et de la rénovation de l'installation de chauffage sur les consommations d'énergie dans les logements construits avant 1975*], ref. 7152 (2008) 97p

DGEC (2008), General Directorate for Energy and Climate, PEGASE Enery price database (2008) http://www.industrie.gouv.fr

French National Assembly (2008), Law's project related to the implementation of the environment round table [*Projet de loi de programme relatif à la mise en œuvre du Grenelle de l'environnement*], 13 octobre 2008, 11p

Geller H. et al. (2005), The experience with energy efficiency policies and programmes in IEA countries, August 2005, International Energy, 40p

Greening L.A. et al. (2005), Energy efficiency and consumption "the rebound effect" a survey, Energy Policy 28 (2000) 389-401

Hong S.H. et al. (2006), The impact of energy efficient refurbishment on the space heating fuel consumption in English dwellings, Energy and Buildings 38 (2006) 1171-1181

INSEE (2002), Household survey – 2001 assessment – dwellings detail [*Enquête Logement – 2001*], CD-ROM

INSEE (2008), Household survey – 2006 assessment [*Enquête Logement – 2006*] (2008)

Jaffe A. et al. (1994), The energy paradox and the diffusion of conservation technology, Resource and Energy Economics, 16 (1994)

Lees E. (2008), Evaluation of the Energy Efficiency Commitment 2005-008, December 2008, 105p, http://www.defra.gov.uk

Ministry of Ecology (2008), Ministry of Ecology, Energy and Sustainable Planning and Development, http://www.legrenelle-environnement.gouv.fr

Ministry of Economics (2006), Ministry of Economic, Finances and Industry, Decree of 19/06/2006 defining standardized energy savings actions, NOR INDI0607665A

Ministry of Employment (2006-a), Ministry of Employment, Social Cohesion and Housing, Decree giving approval on various methodologies for energy performance certificate in metropolitan France [*Arrêté portant approbation de diverses méthodes de calcul pour le diagnostic de performance énergétique en France métropolitaine*] 96p

Ministry of Employment (2006-b), Ministry of Employment, Social Cohesion and Housing, Decree of the 19 july 2006 giving approval of the Th-C-E methodology planned in article 4 and 5 in the decree of 24 may 2006 related to the characteristics of new buldings [*Arrêté du 19 juillet 2006 portant approbation de la méthode de calcul Th-C-E prévue aux articles 4 et 5 de l'arrêté du 24 mai 2006 relatif aux caractéristiques thermiques des bâtiments nouveaux et des parties nouvelles de bâtiments*] NOR SOCU061626A

Ministry of Employment (2007), Ministry of Employment, Social Cohesion and Housing, Energy Performance Certificate – Guideline for the diagnostician V2 [*Diagnostic de performance énergétique – Guide à l'usage du diagnostiqueur V2*] 89p

Perrenoud (2007-a), DPEWIN – Energy performance diagnosis, version 1.1.1

Perrenoud (2007-b), U21W0 – thermal regulation calculation 2005, individual housing, version 4.3.1

Promotelec (1995), Residential buildings, thermal study and insulation [*Locaux d'habitation, étude thermique et isolation*], 4th edition (1995) 144p

Target Media (2008), Guideline for heat pump, http://www.guide-de-la-pompe-a-chaleur.com

Train K. (1985), Discount rates in consumers, energy-related discussions: a review of the literature, Energy 10, 1243-1253

Acknowledgments

D. De Cacqueray, G. Binet and S. Nosperger from EDF-R&D are gratefully acknowledged for helpful contribution on retrofitting prices and refurbishment field study.

Appendix A

The intermittency factor (I) takes into account the inertia of the building envelope, the scenario of energy management (I_0) and the theoretical energy needs (G) calculated as following the 1988 thermal regulation (RT1988) methods (Promotelec, 1995):

$$I = \frac{I_0}{1 + 0.1 * (G + 1)} \qquad (6)$$

As our case study is an old individual house with medium inertia and no energy management device, I_0=0.86. The energy needs G (W/°C.m^3) are calculated as the sum of thermal losses from the buildings shield LS and from the air flow RA divided by the volume of heated space (S*h):

$$G = \frac{LS + RA}{S * h} \qquad (7)$$

Buildings envelope losses are previously calculated with RT2005 method, LS=765.04 W/°C, and RA are the losses from the ventilation flow, RA=99.62 W/°C as calculated following RT1988 method.

Appendix B

Table 9: Financial indicators for windows replacement. n=35 years.

Windows	Arithmetic mean	Median	Standard deviation	Minimum	Maximum
CSE_{10}	485	389	376	66	1383
CSE_n	211	169	163	29	601
BET	63	50	49	9	179
IRR_{10}	-23%	-25%	12%	-37%	1%
IRR_n	-1%	-2%	6%	-8%	11%
NPV_{10}	-4338	-4336	1770	-6838	-654
NPV_n	-2260	-3424	3637	-6402	5362

Table 10: Financial indicators for loft insulation. n=35 years.

Virgin loft	Arithmetic mean	Median	Standard deviation	Minimum	Maximum
CSE_{10}	47	30	47	6	181
CSE_n	20	13	21	3	79
BET	6	4	6	1	23
IRR_{10}	30%	21%	36%	-16%	123%
IRR_n	36%	26%	31%	2%	123%
NPV_{10}	2082	1180	2508	-1483	6026
NPV_n	7404	4391	6109	-469	16019

Table 11: Financial indicators for internal wall insulation. n=35 years.

Walls	Arithmetic mean	Median	Standard deviation	Minimum	Maximum
CSE_{10}	52	36	35	16	140
CSE_n	23	16	15	7	61
BET	7	5	5	2	18
IRR_{10}	14%	15%	16%	-12%	46%
IRR_n	21%	21%	12%	4%	48%
NPV_{10}	2192	3505	3223	-3570	6869
NPV_n	12360	16810	7560	88	20970

Table 12: Financial indicators for gas condensing boiler. n=16 years.

Condensing gas boiler	Arithmetic mean	Median	Standard deviation	Minimum	Maximum
CSE_{10}	137.7	119.8	84.5	37.5	335.4
CSE_n	95.8	83.4	58.8	26.1	233.5
BET	8	8	4	3	17
IRR_{10}	6%	3%	12%	-11%	34%
IRR_n	12%	10%	10%	-2%	36%
NPV_{10}	741	-357	3895	-4796	8668
NPV_n	4432	3663	5637	-2976	15491

Table 13: Financial indicators for heat pump. n=16 years.

Heat pump	Arithmetic mean	Median	Standard deviation	Minimum	Maximum
CSE_{10}	348.7	182.9	392.8	28.8	1689.4
CSE_n	55.9	36.8	41.5	5.8	127.4
BET	18	12	17	1	52
IRR_{10}	2%	-6%	25%	-26%	74%
IRR_n	9%	2%	22%	-13%	75%
NPV_{10}	-529	-1853	8277	-10847	16649
NPV_n	3884	-946	11803	-9955	26705

Table 14: Financial indicators for SDHW. n=16 years.

SDHW	Arithmetic mean	Median	Standard deviation	Minimum	Maximum
CSE_{10}	597.3	542.5	269.8	248.6	1387.4
CSE_n	415.8	377.6	187.8	173.1	965.8
BET	15958	237	34415	43	127714
IRR_{10}	-42%	-40%	16%	-72%	-23%
IRR_n	-26%	-24%	14%	-52%	-11%
NPV_{10}	-7186	-6411	2646	-12280	-4053
NPV_n	-6882	-6317	2678	-12279	-3632