Energy efficiency and CO2 mitigation scenarios for French dwellings based on retrofitting and best energy demand technologies

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Abstract
Two main targets of European and French energy policies are reduction of energy dependency and greenhouse gas mitigation. Energy conservation is unavoidable in order to reach these two goals.

The Building sector is the largest end use in Europe, and also the largest CO_2 emitter (if power plant emissions are included in final energy consumption). It is now well admitted that drastic decrease of buildings energy consumption and CO_2 emissions need an intensive retrofitting of building stock, especially housing.

This work evaluates various refurbishment scenarios outlook for 2030 of French dwelling stock: Business As Usual (BaU) or accelerate rates, usual technologies or Best Available Technologies (BATs). Emerging technologies (not yet available but with strong potential) are introduced among "on the shelf" technologies. Studied scenarios include energy efficiency actions as well as energy substitution. Estimations of technical investment cost of studied scenarios are presented.

The calculations are done using the MI*e*L « Modeling of the Impact of Energy measures for housing » software, developed by EDF and built following a bottom-up approach.

Introduction
Two of the major themes of European and French energy policies at the moment are improved energy independency and the effort to reduce climate change. An ambitious energy conservation policy would serve these two objectives. Buildings (commercial and dwelling) are the largest final energy consumers in Europe as a whole and in France (more than 40 % of the total). They represent one of the greatest potential of energy savings, very largely related to renovation of existing buildings due to the very low renewal rate of buildings. Therefore, renovation of existing buildings appears inevitable. In this paper we only deal with space heating energy as it represents 70 % of the total consumption of household.

This document explores a scenario (BAT) with a large reduction in heating consumption in the residential sector by 2030 based on Best Available Technologies (BATs) with current renovation rates. Two other scenarios are also produced in comparison: the impact of new construction on energy consumption with no refurbishment of existing buildings (REF), complemented by a scenario with a retrofitting by trend (Business as Usual) (BaU).

Modeling of the impact of energy measures in housing
The calculations are done using the MI*e*L « Modeling of the Impact of Energy measures for housing » software, developed by EDF and built following a *bottom-up* approach (i.e. a technical-economic model aggregating each individual measures). No further description of this tool will be provided in these pages as it was described elsewhere [1]. With the MIEL software we only calculate the energy consumption of main homes excluding second homes.

Definition of scenarios

Three types of actions are necessary to achieve a drastic reduction of energy consumption in the housing stock:

1. Energy modesty (effective energy) to change our behavior and make us less energy-consuming,
2. Energy efficiency that can be of three forms in heating: thermal renovation of construction, replacement of heat generating equipment by more efficient equipment, and better management of heating (« heat where I am and when I am there »).
3. Coverage of needs by production of decentralized renewable energies (in the case of heating: wood boilers and heat pumps).

We will only consider the impacts of technical operations (point 2, 3) in this study, and not potential savings related to behavior (point 1), although these potential savings are quantified in some predictive studies [2]. These impacts of technical operations will be firstly quantified for « constant behavior », in other words ignoring the rebound effect (that limits the expected energy saving when the energy efficiency of a home is improved [3,4]). Furthermore, the defect in renovation practices due to bad workmanship is also not taken into account. Nevertheless, the effect of these two last points on consumption is roughly estimated in the discussion part.

REFERENCE SCENARIO: CONTRIBUTIONS OF NEW CONSTRUCTION TOWARDS CHANGES IN HOUSING STOCK CONSUMPTION

In the reference scenario (REF), the housing stock (main houses) will not be renovated and the stock is reducing at the annual rate of demolitions of 16 000/year [5]. The energy performance of new construction is improving at the rate announced in Thermal Regulations: 15 % lower consumption every 5 years. This five-year improvement is imposed on heating consumption in new homes without any description of associated technical solutions. Same assumptions for new homes and demolitions are also restraint for all scenarios.

BUSINESS AS USUAL SCENARIO: ENERGY EFFICIENT RENOVATION BY TREND OF THE HOUSING STOCK

It is difficult to estimate the future impact of the renovation of existing housing following the « trend ». Rates are known due to the housing enquiry [6], but they are counted as renovation « operations », that theoretically introduce an energy saving for the home concerned. In practice, it is very difficult to convert these savings into saved kWh. However, an attempt is made in the BaU scenario with the assumptions presented here. Following three kinds of actions are studied:

- building shield refurbishment: double glazing, wall and roof and floor insulation (table 1).
- retrofitting of heating system without energy switch: low temperature boilers and direct electrical heating systems (table 2),
- substitution of energy during retrofitting of the heating system (table 2).

Special care has been taken in determining annual renovation rates for each of the estimated operations. Assumptions are compatible either with existing rates achieved by the « building » industry for proven techniques (roof spaces, glazing), or with feasible changes to trades remaining consistent with the existing rates in the industry for operations that are not frequently done in France (external insulation, floors, high temperature heat pumps). We must keep in mind, due to our assumptions, that the BaU scenario is already energy efficiency oriented.

BAT SCENARIO: RENOVATION OF THE HOUSING STOCK WITH BEST AVAILABLE TECHNOLOGIES

In the BAT scenario, we will consider the same technical operations for renovation of the housing stock as for the BaU scenario but with better energy efficiency or better technologies (condensing boilers, standard [HP] and high temperature heat pumps [ht-HP]) (Table 1, Table 2). Moreover, new actions are planned based on energy substitution in accordance with the idea of a large reduction of fuel and liquefied petroleum gas (LPG) heated dwellings and no inefficient energy substitution.

Heating energy consumption until 2030

REFERENCE SCENARIO: CONTRIBUTIONS OF NEW CONSTRUCTION TOWARDS CHANGES IN HOUSING STOCK CONSUMPTION

The situation modelled for the year 2000 is similar to the results of studies on changes to the existing housing stock [7]: 24 million main homes heated for a final heating energy consumption (including wood) equal to 377 TWh/year. In 2030, the assessment of a stock of 32 million of main homes is similar to the number of previous studies [8,9].

In 2030, the housing stock will consume 13 TWh/year less than in 2000 for heating due to demolition and houses removed from the housing stock (the existing stock is not renovated in this scenario), and new housing contributes to an increase of almost 46 TWh/year, namely consumption of 410 TWh/year in 2030 compared with 377 TWh/year in the year 2000.

BUSINESS AS USUAL SCENARIO: RENOVATION BY TREND OF THE HOUSING STOCK

The heating consumption of the BaU scenario predicts a global consumption of the housing stock (new and retrofitted existing one) of 186 TWh in 2030 (-2.3 %/yr). The renovation of the housing stock, from 2000 to 2030, allows a decrease of heating energy consumption of 225 TWh.

BAT SCENARIO: RENOVATION OF THE HOUSING STOCK WITH BEST AVAILABLE TECHNOLOGIES

The heating consumption of the BAT scenario gives a global heating consumption of the housing stock of 126 TWh in 2030 (-3.6 %/yr). The renovation of the housing stock, from 2000 to 2030, leads to an amount of heating energy savings of 285 TWh.

Table 1: Building shield retrofitting assumptions for BaU and BAT scenarios. A linear decrease of the thermal transmittance is chosen between 2000 and 2030. Initial thermal transmittance is chosen as the actual average value of old building stock (built before 1975). Value for BaU scenario in 2030 is expected to reach today BAT value.

Refurbishment operation	BaU Technical characteristics (final thermal transmittance)	BAT Technical characteristics (final thermal transmittance)	Unit annual rate (units/year)	Cost (€) price ex VAT excluding subsidies before initiation of the tax credit.
Double glazing	U 2000 : 2.5 W/m².K U 2030 : 1.3 W/m².K	U 2000 : 1.3 W/m².K U 2030 : 0.5 W/m².K	270 000	2000 cost: 4500 2030 cost: 4000
Roof spaces	U 2000 : 0.25 W/m².K U 2030 : 0.16 W/m².K	U 2000 : 0.16 W/m².K U 2030 : 0.15 W/m².K	200 000	2000 cost : 1000 (including 50% in "do-it-yourself") 2030 cost: 1000
Floors	U 2000 : 0.49 W/m².K U 2030 : 0.31 W/m².K	U 2000 : 0.31 W/m².K U 2030 : 0.2 W/m².K	80 000	2000 cost: 1900 2030 cost: 1700
External insulation	U 2000 : 0.56 W/m².K U 2030 : 0.34 W/m².K	U 2000 : 0.34 W/m².K U 2030 : 0.25 W/m².K	70 000	2000 cost: 6500 (with face lifting) 2030 cost: 4500
Internal insulation	U 2000 : 0.56 W/m².K U 2030 : 0.34 W/m².K	U 2000 : 0.34 W/m².K U 2030 : 0.34 W/m².K	230 000	2000 cost: 3900 2030 cost: 3900

Table 2: Heating system retrofitting assumptions for the BaU and BAT scenarios. Price ex VAT excluding subsidies before initiation of the tax credit.

Initial energy	Final energy	BaU			BAT		
		Efficiency (2000/2030)	average annual rate (units/year)	Year 2000 Cost (€) (variation to 2030 in %)	efficiency (2000/2030)	average annual rate (units/year)	Year 2000Cost (€) (variation to 2030 in %)
gas	gas	0.7/1.05	365 000	3800 (+50%)	1.05/1.05	365000	6800 (-15%)
fuel	fuel	0.66/0.98	62 800	5200 (+32%)	0.98/0.98	62 800	8100 (-15%)
LPG	LPG	0.66/1.0	12 000	5200 (+32%)	1.0/1.0	12 000	8100 (-15%)
fuel	gas	0.7/1.05	56 600	3800 (+50%)	1.05/1.05	104 000	6800 (-15%)
fuel	electricity	0.95/0.95*	8 500	1700 (0%)	2.5/2.5**	20 000	16300 (-30%)
fuel	wood	0.65/0.75	7 800	18800 (-40%)	0.65/0.75	17 500	18800 (-40%)
LPG	gas	0.7/1.05	4 200	3800 (+50%)	1.05/1.05	3 300	6800 (-15%)
LPG	electricity	0.95/0.95*	7 100	1700 (0%)	2.5/2.5**	15 000	16300 (-30%)
LPG	wood	0.65/0.75	1 700	18800 (-40%)	0.65/0.75	3 300	18800 (-40%)
LPG	fuel	0.66/0.98	3 500	5200 (+32%)	0.99/0.99	1 000	8100 (-15%)
Electricity*	gas	0.7/1.05	14 900	6700 (+30%)	1.05/1.05	17 000	9700 (-10%)
Electricity*	fuel	0.66/0.98	2 600	8100 (+20%)			
Electricity*	LPG	0.66/0.98	800	8100 (+20%)			
gas	electricity				2.5/2.5**	8 500	16300 (-30%)
Electricity*	electricity				2.5/2.5**	54 000	5000 (0%)

Electricity = *convector heater, **heat pump. Potential enhancement of energy efficiency to 2030 for wood boiler and heat pump aren't taken into account.

Discussion: comparing the scenarios

BaU calculation of existing dwelling refurbishment, from 2000 to 2030, lead to a trend of –3.5 kWh/yr.m² and -4.4 kWh/yr.m² for the BAT scenario. In the past, from 1975 to 1998, energy saved due to housing retrofitting was assessed to -3.8 kWh/yr.m² (energy savings of 120 TWh)[v]. Despite of a low total energy consumption for heating in 2030 according to the BaU scenario, effort of renovation appears in the same order than in the past while the BAT effort is stronger. We have to keep in mind that the past retrofitting of housing stock was easier in term of energy saving by dwelling because of the weaker efficiency of older buildings. At the opposite, the energy savings is overestimated in our calculations, as we have not taken into account the rebound effect and the discrepancy in renovation practices. The rebound effect was estimated from 10 % to 30 % by previous works for heating use [10]. In the other hand, bad workmanship on insulation refurbishments in UK was estimated by S.H.Hong et al. from 13 % to 20 % [iv]. These two points are inescapable and could decrease significantly expected savings up to 2. We choose, a rough estimation, a reduction of 44 % of potential energy savings as presented in the figure 1.

Comparing the two scenarios, we must keep in mind that the BaU is already a hard program and even though the BAT scenario appears of the same order as BaU, it is more efficient for CO_2 mitigation.

CO_2 emissions

The 2030 BaU and BAT CO_2 emissions calculated, with the adjustment of -44% reduction of savings, lead to 48.5 $MtCO_2$ and 42.3 $MtCO_2$, respectively. The CO_2 emission of the year 2000 is estimated at 70.2 $MtCO_2$. We have to keep in mind, as for the energy savings, the CO_2 mitigation calculated are overestimated.

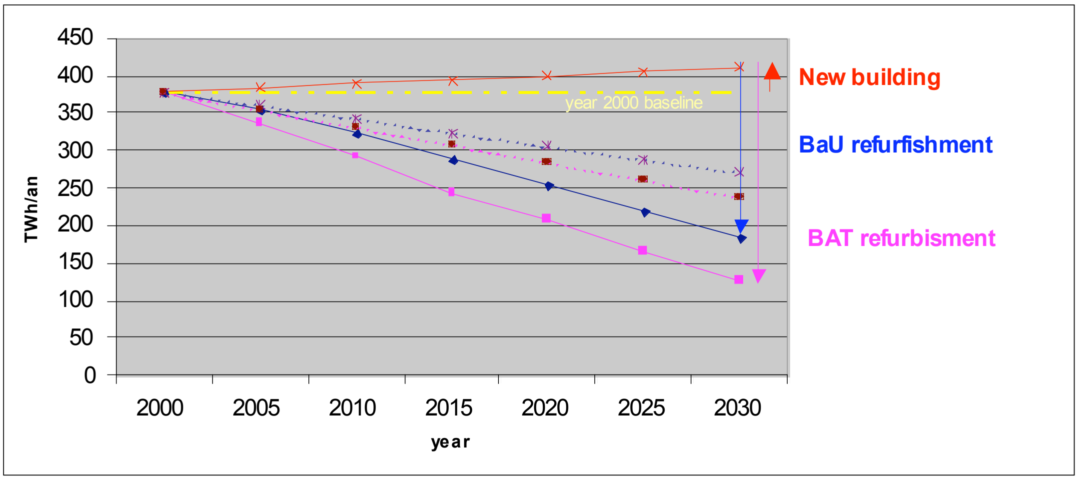

Figure 1: heating energy consumption of dwellings for REF (red), BaU (blue) and BAT (pink) scenarios from 2000 to 2030 (dotted line with rebound effect [-30 %] and bad workmanship in renovation practices [-20 %]).

Cost

The annual average cost of refurbishment in the BaU scenario would be about 5.4 billion €/year compared to less than 8 billion €/year in the BAT one. The expense in the BAT scenario is higher due to use of some expensive technologies (ht HP, condensing boiler, wood boiler), which are not today widespread on the market. Obviously, future prices will significantly decrease.

Comparing the two scenarios, the average cost of refurbishment action is 3700 € and 5000 € respectively for BaU and BAT scenario. These results should be compared with the evaluation of the existing « energy renovation » market (renovation operations that theoretically had an impact in reducing energy consumptions of the home). This market is worth 6 to 9 billion €/year depending on the source and method of processing [[11],vi,[12]]. The assessments of the total cost of renovation program calculated in the BaU and BAT scenarios are smaller because we didn't describe the whole energy refurbishment operations in the calculation.

Conclusion

The set of measures evaluated in the BAT scenario would give a total heating energy consumption to 2030 of 126 TWh to compare with 2000 consumption of 378 TWh, let be a reduction by 3. Obviously, energy saving is too high due to not consideration of rebound effect and discrepancy. These two phenomena, which can drastically reduce energy efficiency of retrofitting, are of a great importance and have to be studied and included in further evaluations. Special attention have to be given to the assessment of the real energy savings, compared to calculated ones. It is a condition of success in describing effects of energy efficiency measures included in policies dedicated to achievement of energy and CO_2 saving targets.

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