A retrospective of 35 years of old dwellings refurbishment to enlighten the future of energy efficiency in buildings: what and who benefits?

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Keywords

retrofit, behavioural change, heating, energy savings, residential buildings, rebound effects

Abstract

Before the first oil crisis, the majority of new buildings in European countries were constructed without any energy efficiency obligation. In those times, Space Heating (SH) consumptions accounted for more than 80 % of the total energy consumption of residential sector. In France, SH in dwellings was rated at 300 $kWh_{fe}/(year.m^2)$, final energy.

40 years later, SH is only 60 % of total consumptions and the unitary SH consumptions have been cut by almost 50 %. Unitary decrease has been sufficiently strong to decrease the total SH consumptions despite increases of numbers and size of dwellings and standards of comfort.

This paper studies the causes of this spectacular decrease: what are the respective responsibilities of demolition, refurbishment of existing housing stock, efficiency of new dwellings and daily behaviour?

A particular attention is given to pre-1975 dwelling stock. The pre-1975 French dwelling stock still represents more than 50 % of Primary Residences (PR) in France and 2/3 of SH consumptions. Due to slow renewal of the stock, it will constitute almost 40 % of PR by 2050 in a Business as Usual Scenario. Understanding the past benefits of retrofitting of this specific stock is important to forecast future consumptions as well as to design future policies.

Our analysis is based on SH energy consumptions time-series from 1973 to 2012 of dwelling's; different vintages and various building census.

In our paper, behavioural evolutions are quantified with the calculation of Space Heating Intensity Factors (SHIF). This indicator is the ratio between observed SH consumptions and EPC (Energy Performance Certificate) normative ones. SHIF is used in literature and considered as a proxy of households' behaviour regarding SH consumptions and thermal comfort.

SHIF has been estimated for the pre-1975 dwelling stock by 1975 and by 2009 to determine if the increase of efficiency has been partly transformed in "increased" comfort or not.

Quantifications of these four main identified drivers (demolition, refurbishment, new dwellings efficiency and behaviour) are proposed. Quite surprising results like evolutions of SHIF are discussed.

Introduction

It is now well know that the European dwelling stock is aged and that most of residential buildings were built without any energy efficiency requirements. It is also now admitted that very efficient new buildings will not be sufficient to decrease drastically energy consumptions and CO_2 emissions by 2050. For instance, existing studies (Traisnel, J.P., 2001) have proved that a deep retrofitting of existing stock and decrease of unitary CO_2 content of kWh are both necessary to cut Space Heating (SH) of the residential sector CO_2 emissions by 4 (see Figure 8). Consequently, building stock refurbishment is identified as a key action in order to reach European ambitious energy policy targets.

This paper tells the story of the past 40 years for old (built before 1975) French dwellings refurbishment. Does the level of energy efficiency improvement of the stock in the past has the

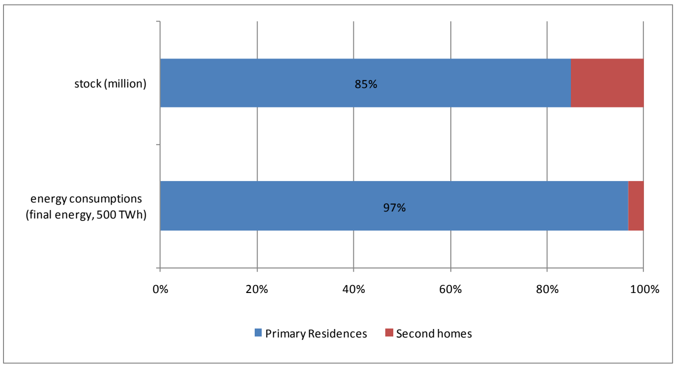


Figure 1. Comparison of respective responsibilities of Primary Residences in dwelling population and energy consumptions shares (TWh climate adjusted, 2010, source: CEREN).

same order of magnitude that the effort which is necessary in the next 35 years to reach future energy policy goals?

Concerning energy consumptions of all sectors, European target is a decrease of 20 % (primary energy) by 2020 compared to a Business As Usual (BAU) forecasting made in 2005 (EU, 2006). It is now assumed that energy savings are more achievable for buildings than for other sectors (Giraudet, L.G., 2011). In France, specific target have been defined for buildings (Grenelle, 2008): decrease of 38 % of *existing* dwelling consumptions (final energy) during the 2009–2020 periods (11 years, annual rate: -4.25 %). We will compare these necessary future rates with past ones.

Warning

By 2010 the French dwelling stock accounts 33 million houses. Only 28 million (85 %) are Primary Residences (PR), but they represent 97 % of the stock's final energy consumptions. Consequently, available data are focused on this specific stock and this paper studies only PR consumptions.

French dwelling stock (primary residences): from 1973 to 2010

WHY 1973?

It is not possible to work on energy efficiency in buildings in Europe without knowing that 1973, year of the first oil shock, have drastically changed the way to address the building construction and design. After 1973, energy services were not only considered as a question of comfort. It was as a concern for energy consumptions (synonymous of important expenditure for households) and national commercial balance disequilibrium (energy consumptions, even in buildings, were mostly imported fossil energies, especially oil). In France, and in a majority of western European countries, 1975 is the first year of implementing requirements for energy efficiency for new dwellings. Before 1975, a very large majority[1] of the dwelling stock (existing and new ones) were not insulated at all.

1. In France, a specific segment of new dwellings, equipped with electric heaters, considered as very modern equipment compared to fossil boilers, were designed and built with a minimum thermal insulation and energy management.

WHAT EVOLUTIONS OF DWELLING STOCK SPACE HEATING CONSUMPTIONS SINCE 1973?

It is always interesting to analyse past phenomena to understand the possible futures. Prospective people and forecasters are found of past tendencies; especially to analyse the dwelling stock which evolutions are very slow; at least in the European countries.

During the 1973–2010 period (37 years), French PR stock increased by 60 % and total Space Heating (SH) consumptions decreased by 14 %. These opposite evolutions are due to a spectacular decrease of unitary SH consumptions on the same period (-67 %). Table 1 summarizes the different indicators describing the dwelling stock and its energy consumptions during this period.

The past global decrease of dwelling energy consumption is due to a spectacular decrease of unitary consumptions per m². The Figure 2 shows that SH unitary consumptions (kWh_{fe} (/m².year)) decrease significantly more than total ones for all PR dwelling stock.

What are the causes of the spectacular decrease of Space Heating unitary consumptions since 1973?

Four main causes of these evolutions can be identified:

- Output (demolition, reallocation …) of dwellings from the PR (Primary Residences) existing stock;
- Increase of energy efficiency requirements (thermal regulation) for new dwellings;
- Retrofitting of existing buildings;
- Changes in households' behaviour.

DEPARTURE OF DWELLINGS FROM THE EXISTING STOCK:

It is a fact that – for instance – the number of PR built before 1975 have decrease by 6 % by 2012. We can imagine that demolition is the first cause of this decrease. But we must keep in mind that we are dealing with the PR dwelling stock and not with the entire building stock which includes vacant units and second homes. Movements inside the entire dwelling stock are permanent. Every year, an important number of dwellings change their status: some PR become vacant or second homes, others can be converted to Tertiary buildings or demolished. We must consider that during the same year, opposite movements exist and Tertiary buildings, vacant and second homes can be turned to PR. We have to consider annual balances between these different stocks to address the evolution of PR stock and its thermal efficiency (Traisnel, J.P., 2001).

We must also consider that large houses can be divided in several ones, and small ones (or apartments) can be joined. This phenomenon explains the non-intuitive fact that the specific 1949–1974 PR dwelling stock has increased by 17 % between 1975 and 2012 (see Figure 3) while all pre-1975 PR stock has decreased by 6 %. This global decrease is due to the important pre-1949 PR stock (Figure 3).

Due to periodic census, it is possible to check the global evolution of PR dwelling stock.

Table 1. Evolution of dwelling (PR) stock and its energy consumptions during 1973–2010 periods (Source: CEREN, final energy, climate adjusted data).

	1973	2010	increase
number of dwellings (million)	17,020	27,245	1,60
average dweling surface (m²)	72,0	91,0	1,26
total dwelling surface (million m²)	1225,4	2479,3	2,02
total final energy consumption (TWh/year)	447,7	483,5	1,08
SH total consumption (TWh/year)	381,5	329,4	0,86
DHW total consumption (TWh/year)	31,2	50,2	1,61
cooking consumption (TWh/year)	18,5	28,0	1,51
electric appliances consumptions (TWh/year)	16,4	75,9	4,62
total unitary consumption per dwelling (MWh/(year.housing)	26,3	17,7	0,67
SH unitary consumption per dwelling (MWh/(year.housing)	22,4	12,1	0,54
DHW unitary consumption per dwelling (MWh/(year.housing)	1,8	1,8	1,00
cooking unitary consumption per dwelling (MWh/(year.housing)	1,1	1,0	0,94
electric appliances unitary consumption per dwelling (MWh/(year.housing)	1,0	2,8	2,89
total unitary consumption per dwelling (kWh/(year.m²)	365,3	195,0	0,53
SH unitary consumption per dwelling (kWh/(year.m²)	311,3	132,8	0,43
DHW unitary consumption per dwelling (kWh/(year.m²)	25,5	20,3	0,79
cooking unitary consumption per dwelling (kWh/(year.m²)	15,1	11,3	0,75
electric appliances unitary consumption per dwelling (kWh/(year.m²)	13,4	30,6	2,28

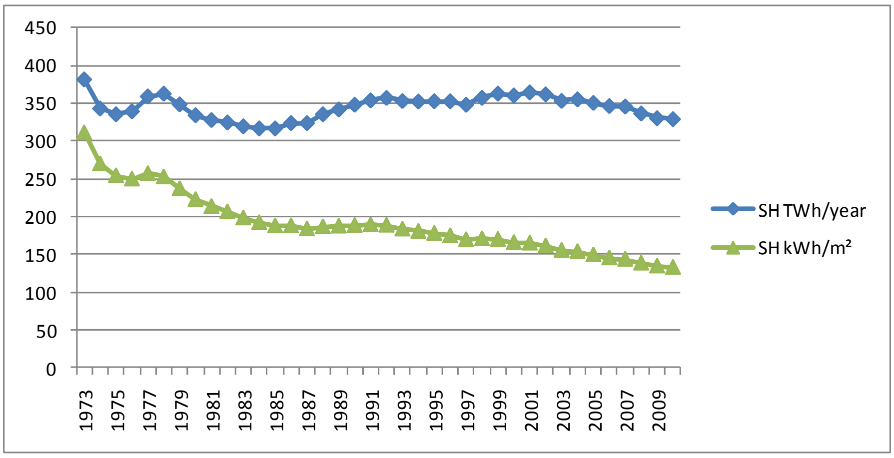


Figure 2. Evolution of total and unitary Space Heating (SH) consumption of PR stock (source: CEREN, climate adjusted final energy: TWh_{fe}/year and $kWh_{fe}/[m^2.year]$).

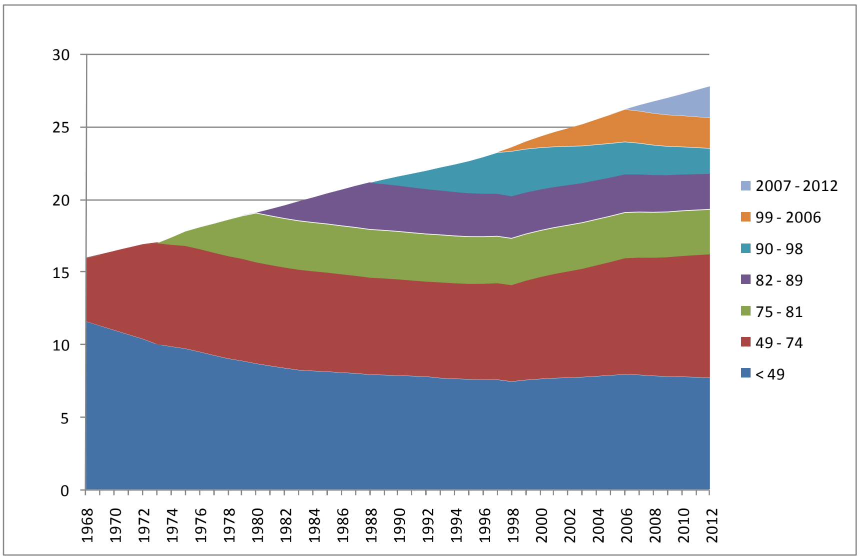


Figure 3. Evolution of French Primary Residences stock depending on the year of construction (million), source: CEREN.

INCREASE OF ENERGY EFFICIENCY REQUIREMENTS FOR NEW DWELLINGS: WHAT OBLIGATIONS FOR NEW DWELLINGS SINCE 1975?

Since 1975, it is possible to quantify the evolution of efficiency standards and requirements for new buildings according to the "thermal regulations" texts. First requirements were dedicated to the building envelope performance. Minimum standards of thermal losses have been defined in the first thermal regulation (RT74). Consequently, the perimeter of the obligations was only on the building fabric and only targeting SH. The considered energy level was the "useful energy" and calculations were made with a normative SH comfort and management scenario: 19 °C indoor temperature for all rooms, very small decrease of temperature during night and vacant Figures 4 & 5 show the evolution of minimal normative requirements for new dwellings thermal insulation expressed as unitary losses (per m^2 [living area] or per [supposed] heated m^3).

During the following years, requirements have been expressed in successive thermal regulations[2], as maximum normative consumptions (final energy) including:

- Energy services related to the design of the building and its energy efficiency: HVAC (Heating, Ventilation, Air Conditioning) and lighting;
- Equipments related to thermal appliances: heat and cold generators (SH, cooling, DHW: Domestic Hot Water) and HVAC auxiliaries.

More recently, in the current thermal regulation (RT2012), those maximum normative consumptions have even been decreased and are now expressed at the primary energy perimeter. The efficiency of the "energy chain" before the delivery of final energy to the buildings in now considered as a part of the energy efficiency of the building itself.

Figure 6 shows the evolution of standards SH consumptions for new dwellings. Note the important fall by 2012 which is not in the continuity of previous years. Figure 7 compares the evolution of current unitary SH consumptions of dwelling stock and of new dwellings at the same periods. It is remarkable that – before 2012 – normative unitary SH consumptions for new dwellings were 50 % lower than the ones observed for existing dwellings stock.

In 2015, due to drastic increase of requirements of energy efficiency for new dwellings between 2005 and 2012 (see Figure 6), it is now generally assumed that SH energy consumptions of new dwellings are no more a problem and that their thermal insulation has reached an asymptotic level. Future requirements will continue to enlarge their perimeter, including the concept of "building environmental impact" and not only the unitary primary energy consumptions for a restricted number of en-uses.

The 1973 oil shock is the cause of a new concern on energy efficiency and the necessity of knowing how much energy is used in order to help the design of energy policies (creation of International Agency of Energy). It explains why 1973 is a starting point for most of available statistics (on dwelling stock and others sectors) in Europe. Existing field studies show a gap between normative (calculated) and observed SH consumptions for dwellings that have been built after 1975. This gap is due to:

- Actual households' behaviours are different in reality compared to scenarios assumed for the calculation of normative consumptions needed to prove that the building respects thermal regulation requirements;
- It takes time for all the builders to adopt new rules after a new increase of energy efficiency requirement level is enforced. Usually, a 5–10 years delay is assumed. Consequently, it is a fact that a certain % of new dwellings (especially single houses) do not respect all thermal regulation requirements.
- Some post-1975 dwellings have been retrofitted: especially the ones from the 1975–1990 period. For instance, we observe that virgin lofts are insulated every 20 years (Raynaud, M., 2014); windows are changed every 30 years (Laurent, M.H. 2001). On an average, dwellings built between 1975 and 1985 have "new" windows (at least newer than the envelope).

Considering these hypothesis, it is possible to estimate the real SH consumptions for new dwelling built after 1975 for each year between 1975 and now. The real difficulty is to study the evolution of the pre-1975 building stock SH unitary consumptions that are only due to retrofitting actions and behavioural changes and not to improvement of energy efficiency of new dwellings.

RETROFITTING OF EXISTING BUILDINGS

Due to the important age of the French building stock (and more generally for all European countries), energy efficiency renovation of the stock is not an option. It is now known that the increase of energy efficiency of new buildings will not be sufficient to reach the future ambitious targets of public policies (Traisnel, J.P., 2001). The Figure 8 shows that, even if assuming that new dwellings do not consume any kWh for SH (i.e. 0 kWh_{fe}/m^2), the SH dwelling stock consumptions by 2050 will not change if – at the same time – the dwelling stock is not deeply refurbished (second upper scenario, the pink one).

The necessity of deep retrofitting of existing buildings is now well understood for the future. But for the past 40 years, respective contributions of energy efficiency in new dwellings and retrofitting of existing stock concerning the decrease of unitary SH consumptions are not well known. For the French building stock, there is only one study (Traisnel, J.P., 2001) concluding that responsibilities were nearly of the same order of magnitude. With the help of current data, we have calculated new estimations for the 1975–2010 periods (see below).

CHANGES IN HOUSEHOLDS' BEHAVIOUR

With our parents' and grand parents' testimonies, it is easy to understand that households' standards of comfort have changed over the 1975–2010 periods. Generalization of central heating, increase of houses size and increase of average indoor temperature and number of heated rooms are facts.

In United Kingdom, studies have calculated the evolution of average internal temperatures in English houses (Palmer, J., Cooper, I., 2012). These results are not drawn from the monitored performance of homes, but are the result of energy bal-

2. RT82, RT88, RT2000 and RT2005.

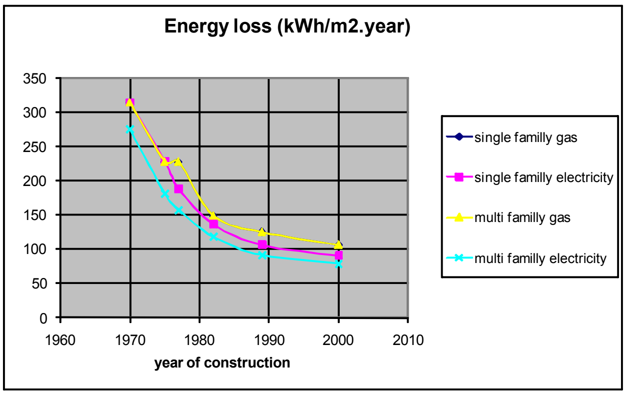


Figure 4. Evolution of building envelope and ventilation energy losses: obligations for French new dwellings 1975–2000 (Duforestel, 2001).

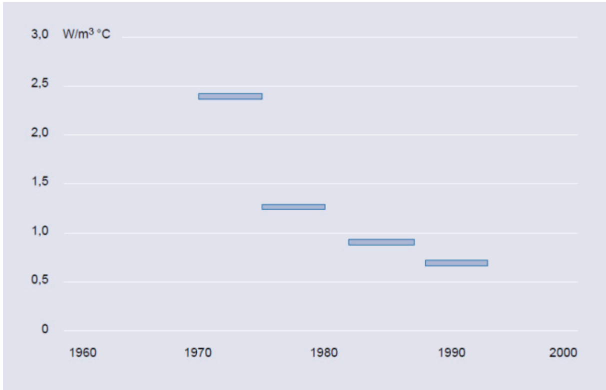


Figure 5. Evolution of G coefficient (W/(m³.°C) for French new dwellings 1970–1989 (Pouget, A., 1989).

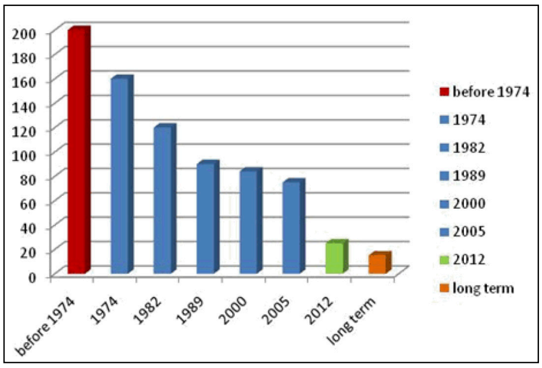


Figure 6. Evolution of normative Space Heating energy consumptions for new dwellings (kWh/m^2, final energy, source: EDF R&D calculations).

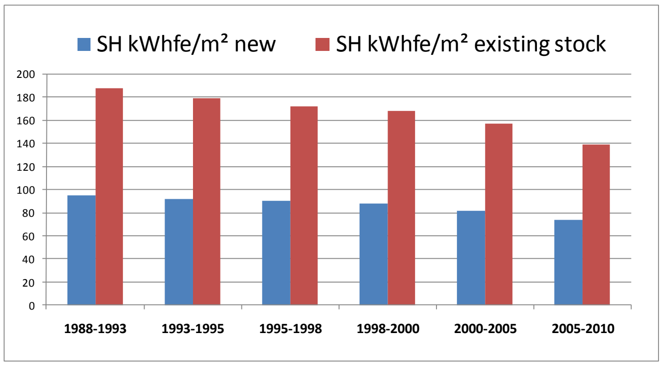


Figure 7. Comparison of evolution of unitary SH consumptions for new and existing dwellings (kWh/m^2, final energy, source: CEREN data).

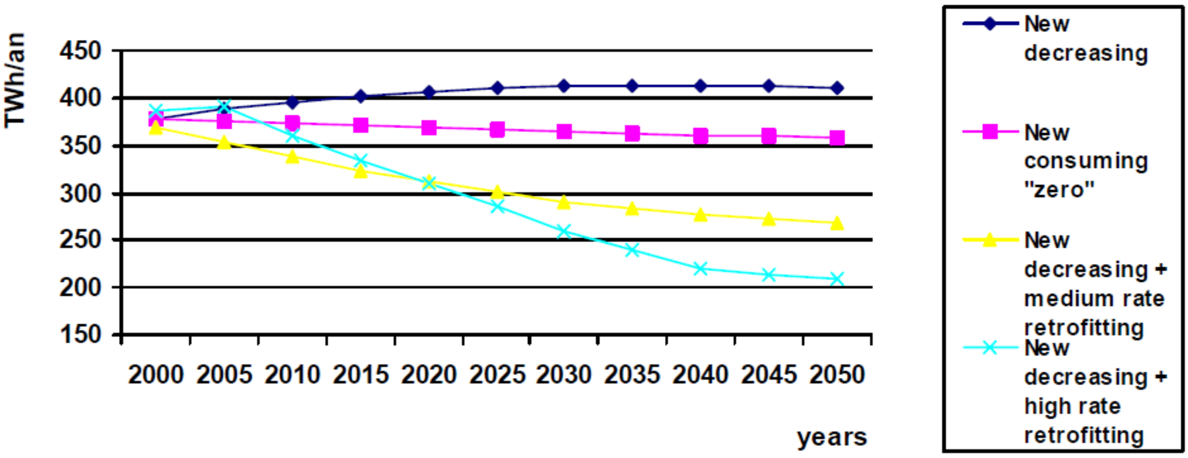


Figure 8. Four scenarios of evolutions of the French dwellings stock SH consumptions (PR) from 2000 to 2050 (source: author's calculations with data from Traisnel, J.P., 2001).

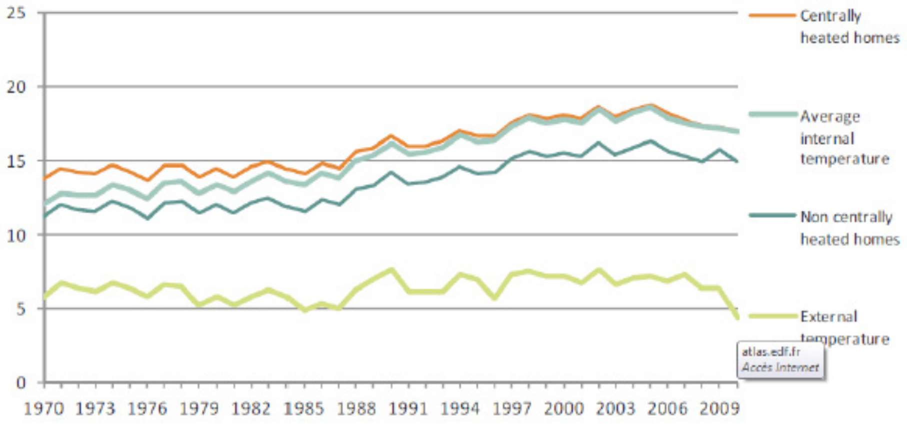


Figure 9. Evolution of average winter internal (calculated) and external temperature (°C) in UK homes (Palmer, J., Cooper, I., 2012).

ance calculations that have been modelled using building physics data, energy consumption figures and assuming that people heat their homes following a normative scenario. They can be considered as an indicator embedding energy performance and households' behaviour. Consequently, the most interesting information does not rely on absolute values (the results give that UK households heat their homes by 16.9 °C in 2009 …), but on relative ones. Since 1970, the average internal temperatures of Britain's homes in winter seem to have gone up by more than 3 °C. French surveys (Households' questionnaires: no measures, no calculations) (CEREN, 2010) were conducted on shorter periods (1990–2008) and show that French household have increased their internal home temperature by almost 1 °C in 18 years. If we assume that internal temperatures have increased by 2 °C during the last 40 years in French dwellings, it could be responsible for an increase of 15–20 % of the SH consumptions.

In another way, different surveys report that numerous French households do not heat their home the way they would like to. According to INSEE survey (Devalière, I., Briand, P., 2011), 14.8 % of French households have declared suffering from coldness during winter 2006. That % had increased since previous survey from winter 2002. Other studies (Raynaud, M., 2014) show that occupants of large single houses often do not heat all the house's rooms.

Recent works introduced the concept of Space Heating Intensity Factor (SHFI) (Sunikka-Blank, M. and Galvin, R., 2012). SHFI is the ratio between the theoretical energy consumption (for instance, based on normative calculation i.e. Energy Performance Certificate: EPC) and the current energy consumptions. A SHIF of 1 means that the unitary energy consumption matches the theoretically expected unitary energy demand. A SHFI below 1 implies a lower demand than expected (under consumption[3]) and a SHIF higher than 1 means that demand is higher than expected (overconsumption). This factor is considered as a proxy of household's behaviour. The lower it is, the lower the thermal comfort is and the higher the behavioural constraint is. In France, the average value of the SHFI for households equipped with individual central heating is 0.62 (Allibe, 2010). That means that - on average – households' SH heating consumptions are 38 % lower than the norm (EPC calculations) says.

We use this concept of SHFI in order to quantify the evolution of comfort of pre-1975 dwelling stock in the second part of this paper.

What matters: new dwellings efficiency obligations or existing stock retrofitting?

If we assume no energy efficiency requirements for the post-1975 dwellings and no retrofitting of existing pre-1975 dwelling stock, the unitary SH consumptions should have remained identical to the pre-1975 ones during the 1975–2010 periods. We can discuss the point that this assumption implies that there is no change in households' behaviour (no increase or decrease of comfort), but this calculation is a good approximation of what could have happened.

With these assumptions and due to the important increase of the building stock surface (m²), 2012 SH consumptions (PR) should be 823 TWh_{fe} (final energy) by 2012 compared to the 309 TWh_{fe} currently observed (Figure 10).

It is possible to estimate the SH consumption of new dwellings during the same period. Comparison with CEREN data (CEREN, 2012) gives good confidence in the calculated results. Subtraction of current SH consumption of new dwellings to their estimated consumption without any energy efficiency gives the volume of savings due to new dwellings efficiency. By 2012, these savings represent 278 TWh_{fe}. Consequently, without any retrofitting of the whole dwelling stock (pre and post-1975), 2012 SH consumptions should be 545 TWh_{fe}. By comparison with the current 2012 SH consumptions, we can provide an assessment of the contribution of retrofitting of the whole stock and behavioural changes: 236 TWh_{fe} by 2012. It is less than the 278 TWh_{fe} due to energy efficiency in new dwellings. For this estimation, we did not take into account behavioural changes. As proposed upper, if we assume that indoor temperature in French dwellings has increased by 2 °C during the last 40 years, the savings due to the stock retrofitting are very close to the savings due to new buildings' efficiency.

3. According to a normative behaviour: 19 °C in all rooms as calculated in the EPC with very little decrease of temperature during night and vacancy.

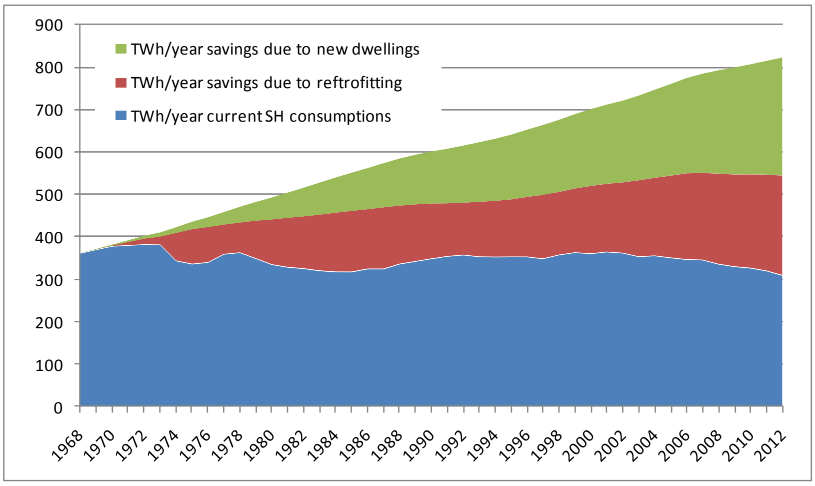


Figure 10. Evolution of SH consumptions: savings due to new dwellings efficiency and existing stock retrofitting (PR, TWh final energy, source: authors calculations and CEREN data for current consumptions).

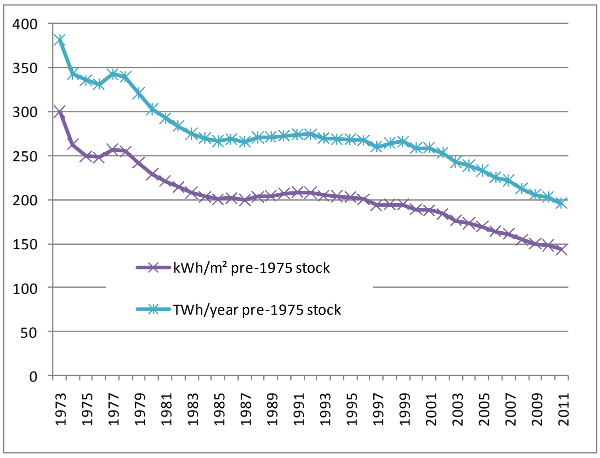


Figure 11. Evolution of unitary and total SH consumptions of pre-1975 dwelling stock (final energy, source CEREN).

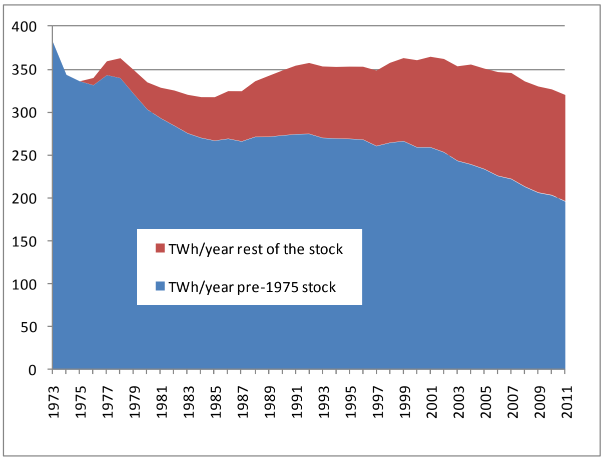


Figure 12. Responsibility of pre-1975 dwelling stock compared to the whole stock in SH consumptions (final energy, source CEREN).

During the last 40 years, the decrease of energy consumption was equally due to the contributions of new dwellings and retrofitting of existing ones. Those effects have erased the increase of number of heated m² and comfort on the SH consumptions.

The last part of our paper is focused on pre-1975 dwelling stock evolution in order to determine if the increase of energy efficiency have been partially transformed into increase of comfort.

Focusing on pre-1975 French dwelling building stock

EVOLUTION OF PRE-1975 FRENCH DWELLING BUILDING STOCK

Inside the French dwelling stock, and due to the fact that it was built before any energy efficiency requirement, the pre-1975 is identified as a priority target in energy efficiency public programmes. It remains today the majority of PR stock (16 million dwellings, 58 % of the PR stock by 2012). Its responsibility in SH consumptions is even higher (61 % by 2011, 196 TWh_{fe}, climate adjusted). Nevertheless, the pre-1975 stock unitary SH 2011 current consumptions are not "so bad": 143 $kWh_{fe}/(m^2.year)$ in comparison with the whole building stock: 133 $kWh_{fe}/(m^2.year)$ for the same year.

During the 1975–2012 periods (37 years), the pre-1975 PR stock decreased only by 6 % due to the splitting of houses built during the 1949–1974 periods (see Figure 3). Due to an increase of average surface, the total (supposed) heated surfaces remained nearly the same during the same period. That is the reason why the decreases of both total and unitary consumptions are nearly identical: -42 % (Figure 13). Savings due to these decreases are estimated to 26 TWh_{fe} by 2011.

French energy efficiency policy (Grenelle, 2008) envisages a decrease of 38 % of existing dwelling consumptions (final energy) during the 2009-2020 periods (11 years, annual rate: -4.25 %). During the last 40 years, we know that higher decreases were observed for unitary SH consumptions (ADEME[4], 2013). Otherwise, the French goal concerns only *existing* build-

4. ADEME is the French National Agency for Energy and Environment.

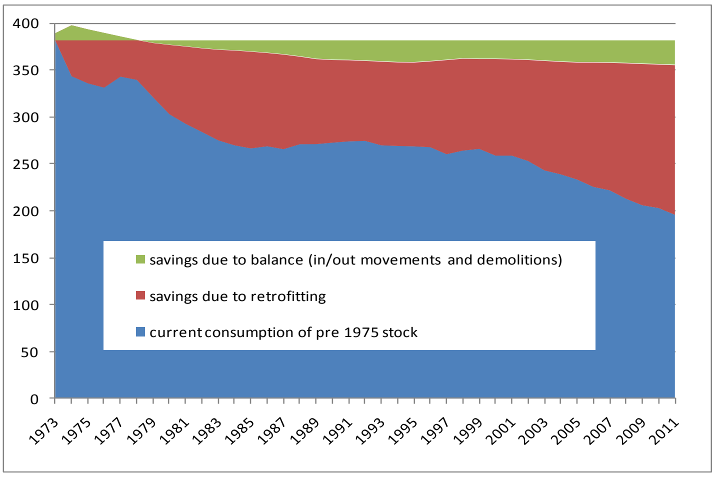


Figure 13. Evolution of pre-1975 dwelling stock SH consumptions: savings due to new dwellings efficiency and existing stock retrofitting (PR, TWh final energy, source: authors calculations and CEREN data for current consumptions).

ings. These two points allow us to compare this future necessary rate (-4.25 %) with the past decrease of unitary consumptions of pre-1975 buildings (the ones existing by 1975) in order to not taking into account the effect of better efficiency of new dwellings. Figure 11 shows that during the last four decades, this observed decrease was really slower (-1.5 %/year). 4–5 % annual decreases have only been observed at the beginning of the period (1979–1983). In a BAU (Business As Usual) way, it does not seem possible to reach Grenelle's target. Previous works (Giraudet, L.G., 2011) have shown that this 2020 goal cannot be achieved if rebound effect is taken into account. In a lower part of our paper, we will envisage if it possible to reach that goal without taking into account rebound effect.

We observe that, at the beginning of the period, the balance between entries and departures (partly due to demolition) was positive. That means that PR coming from other stocks (Tertiary building, vacant and second homes) and splitting of large houses were more important than demolitions, joined houses, and departure to other buildings stocks.

Savings from retrofitting are 159 TWh_{fe} by 2011, which is considerably more than the savings due to movements to other buildings stocks and demolitions.

Without surprise, due to the absence of "new dwelling efficiency effect", for the pre-1975 dwelling stock, the main effect is due to thermal-retrofitting. There is no doubt that energy efficiency of the pre-1975 have increased. But what share of this theoretical increase that has been captured by the "rebound effect" [5] or spoiled by discrepancy?

MORE COMFORT?

Our chosen indicator of the evolution of comfort in pre-1975 dwelling stock is the Space Heating Factors Intensity (SHFI, see definition above). For that purpose, we use data from a 2009 survey representative of the whole French dwelling stock (2,012 households), equipments and occupants (Cayla J-M., Allibe B., 2010). For the study of SH consumptions and households' behaviour, the initial size of the sample was reduced to 923 respondents. Occupants heated with collective heating equipments were excluded due to the fact that they do not have individualized energy bills, and that, in most cases, they cannot manage their heating equipment. It is not possible to quantify SHIF in such situations. The authors also excluded 100 households for whom the final space heating energy consumption does not fall between 20 and 400 $kWh_{fe}/(year.m^2)$. Those extreme values were considered as errors as they are nearly impossible due to existing regulations and other studies on the dwelling stock.

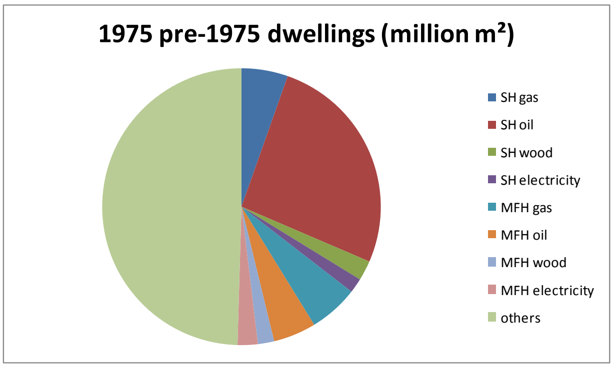
Pre-1975 dwellings are extracted from the whole database. In order to simplify the calculations, we limited the study to houses and apartments equipped with individual SH equipments and heated with only one principal energy. Dwellings heated with a bi-energy system (or even more complex ones) are not studied despite the fact they represent more than 1 million dwellings in the pre-1975 stock. Consequently, only 6 segments are studied:

- Single houses heated with individual boilers (oil and gas), electric heaters and Heat pumps, and wood;
- Apartments heated with individual gas boilers and electric heaters.

For the apartments, it was not possible to consider oil and wood energies due to the fact that oil boilers are collective ones (nearly 0 individual oil boiler,) and that wood was almost not used as individual fuel in apartments by 2009. For dwellings heated with electricity, only direct electric heating was considered by 1975 (nearly 0 heat pumps); but heat pumps were included in the pre-1975 stock by 2009.

The 6 segments represent 44 % of the national residential heated surface in 1975 versus 70 % in 2009. During the last 40 years, dwelling SH landscape has considerably changed: coal has disappeared; oil considerably decreased benefiting to gas, and, at a second range, to electricity. During the same period, the number of equipped households has significantly augmented, and SH systems were simplified (less multi-energy

5. Rebound effect is considered as a change of behaviour before and after retrofitting of their house. The increase in energy efficiency is partially transformed in increase of occupant's comfort. Consequently, the real decrease of consumption (and bill) is lower than the expected one, at least due to behavioural change. Another reason explaining these lower savings is that the retrofitting has not always been correctly made. This second cause is often forgotten when explaining the gap between expected and real savings.



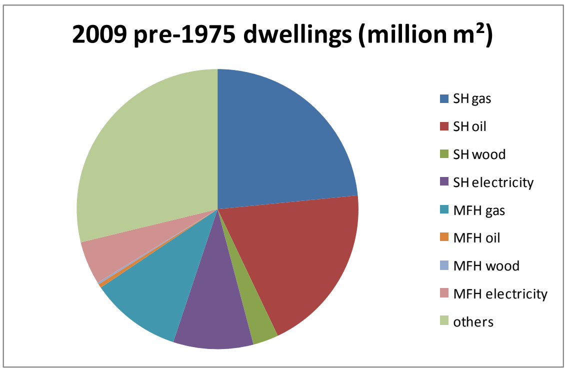


Figure 14. Evolution of pre-1975 dwelling stock: space heating energies (source: authors calculations from CEREN data).

dwellings). Consequently, the 6 same segments are significantly more representative of dwelling stock surface by 2009 than 1975.

Heating factors calculations for 2009 year

In our sample, for each selected respondent, normative SH consumptions were calculated with EPC (Energy Performance Certificate) methods ($kWh_{fe}/(m^2.year)$, final energy) as the survey was conducted in order to collect the data necessary to the calculation. Observed consumptions are deducted from two sources:

- French annual analysis of dwellings consumptions per end-uses and per segments (CEREN, 2010) that gives average values for each studied segments.
- Our sample households' SH heating consumptions were extracted from real energy bills with the help of two models with a multi-linear regression approach with the same method than used in Cayla's paper (Cayla J-M., Allibe B., 2010).

The data from the two sources were compared for average values (SH kWh/m².year) and national SH consumptions (TWh/year) for all segments (not only for the 6 studied segments). Values are matching. For the following calculations, we use CEREN (Centre d'Etudes et de Recherche sur l'Energie)[6] data as estimation of actual SH consumptions.

Pre-existing works – based on the same method – have shown that the French average SHFI for the whole stock of dwellings heated with individual equipments was 0.62 in 2009 (Figure 16). Unsurprisingly, we find lower values for the pre-1975 dwelling stock: 0.50 for the weighted average value of the 6 studied segments. However, this value is more representative of the single houses stock due to its important weight (>80 %) in the total of the 6 studied segments. Behavioural restriction seems to be lower for households leaving in single houses compared to those leaving in apartments heated with individual central heating: respectively 0.52 and 0.41. The average values of the 6 segments are quite close with extremes at 0.40–0.60.

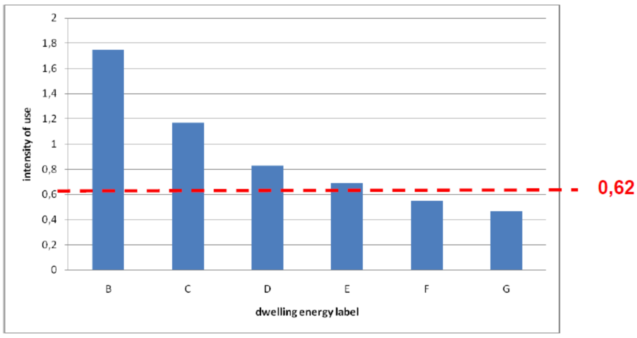


Figure 15. Space Heating Factor Intensity vs energy label class for French dwellings (centralized individual space heating equipment, final energy, (Allibe, B., 2012))

Space Heating Factors Intensity calculations for 1975 year

EPC did not exist by 1975. For each 2009 studied segment (6), we calculate a "1975 EPC" considering that heating equipments' efficiency was lower by 1975 than their values assumed in current EPC data base and that the building envelope were not insulated at all. As EPC is an evaluation of energy efficiency, and not an evaluation of housings real consumptions, EPC is calculated with the same level of comfort by 1975 and 2009. The possible 2 °C increase of average indoor temperature in French dwellings during the same period (see upper) is not taken into account in our calculations.

In our study, we assume that the dwellings considered in the 2009 survey were heated with the same energy by 1975. This assumption can be contested as the different occupants during the 1975–2009 periods could have decided to switch their energy for space heating. It is true at an individual scale but, due to the very high heterogeneity of the residential market, this weakness is less important as we consider average values and due to the fact that the 6 studied segments are large ones. Actual SH consumptions are given from CEREN database.

Not surprisingly, 1975 SHFI are lower than 2009 ones, but not drastically different: average weighted value of 0.44 (compared to 2009: 0.50). An interesting observation is the range of values for the 6 studied segments: from 0.21 to 0.59 (compared to 0.40 to 0.60 by 2009). Heterogeneity of dwelling segments was really much higher by 1975 than today. It seems that varied levels of comfort have merged to an acceptable level.

6. CEREN (Center For Study and Research on Energy) is an energy institute dedicated to survey and analysis of French energy consumptions.

1975–2009 evolutions

Space heating energy efficiency: more energy efficiency?

Concerning Space Heating, it is usually assumed that pre-1975 energy efficiency of dwelling stock has importantly increased with the insulation of buildings' envelopes and the increase of SH equipment's efficiency. EPC calculated consumptions (expressed at a final energy level, which is the perimeter of the dwelling: building envelope + SH equipment) can be considered as a good indicator of energy efficiency *ceteris paribus*. The table below shows that (weighted) mean EPC SH consumptions of the 6 studied segments are divided by 54 % between 1975 and 2009 (-1.8 %/year). This decrease is to be compared with the decrease of unitary current SH consumptions for the same period[7] (-40 %, -1.5 %/an) which is a major part (3/4) of the decrease expected from normative calculations. The comparison of these two figures show that the majority of the increase of dwelling energy efficiency has been "transformed" into decrease of unitary energy consumptions. The rebound effect and the discrepancy were not as important as feared.

All segments have improved their energy efficiency. The SFH (Single Family Houses) stock has more progressed than the MFH (Multi Family Houses) one. It is quite intuitive, but we must keep in mind that we describe the apartments stock with only 2 segments representing less than 20 % of all dwellings of the 6 studied segments, consequently, conclusions on MFH evolutions are less reliable than the one concerning SFH. Comparisons between 1975 and 2009 for each segment are more significant. All segments have improved their SH energy efficiency. The most spectacular improvements are for SFH heated with wood and those heated with individual gas boilers. This is especially true for wood due to the replacement of opened fireplaces with closed ones, the spectacular improvement of wood stoves efficiency and the arrival of wood boilers.

Observed consumptions include rebound effect and retrofitting discrepancy. Energy efficiency has increased with higher rates than consumptions have decreased. If we consider decrease of SH unitary consumptions only due to increase of energy efficiency, the annual rate during 1975–2009 period should have been -1.8 %/year. It is not sufficient to reach 2020 Grenelle's goal (20 % decrease of buildings consumptions). Even without taking into account rebound effect and retrofitting discrepancy, it does not seem possible to reach Grenelle's target in a BAU way.

Space heating level of comfort

It is also usually assumed that thermal comfort has increased in the French dwellings during the last 40 years. As we developed upper, we consider that SHIF can be considered as a valuable assessment of SH comfort level. The increase of SHIF proves that this improvement is real, but not very important (+14 %), and not sufficient to erase the effect of the increase of energy efficiency. This 14 % increase is to compare with the possible increase of 2 °C of average internal temperature. Upper in the text, we have indicated that this 2 °C increase could generate a 15–20 % increase of SH consumptions. These two estimations are coherent.

7. Even if the 6 studied segments do not represent the whole stock of dwellings.

Contrary to the evolutions of energy efficiency, SHIF increased higher for apartments (+31 %) than for single houses (+12 %). Absolute (and higher) values of annual energy bills in SFH compared to MFH could explain that rebound effect affects more SFH.

Another interesting result is that the heterogeneity inside the 6 considered segments has significantly decreased between 1975 and 2009 (more than 50 %). It seems that – on average - households have managed their housing's thermal-retrofitting (building envelope and SH equipments) in order to reach an "average acceptable value of comfort" balanced with an affordable energy bill.

SHIF have increased for all studied segments excepted for SFH heated with oil and electricity that remained nearly unchanged. The most spectacular improvement is for single houses heated with wood (+94 %) and apartments heated with individual gas boilers (+39 %). For the other segments, the merit order of energy efficiency and comfort improvements are not the same. The four SFH segments are the four first regarding energy efficiency improvement, but not for comfort. The combination of absolute values of annual energy bills which are higher for SFH than for MFH and the variety of considered SH energy prices partly explains these differences. Studied SFH segments with highest energy prices (oil and electricity (ADEME, 2014) have the smallest increases of comfort. The case of SFH heated with wood is specific and due to spectacular increase in energy efficiency of wood SH equipments.

Conclusions

During the last four decades, retrofitting of existing dwelling stock (especially pre-1975 one) and requirements of minimum levels of energy performance for new buildings have both contributed to a spectacular decrease of Space Heating unitary consumptions. Roughly, 50 % of the decrease is due to retrofitting and 50 % to new dwelling efficiency.

Average observed unitary Space Heating consumptions ($kWh_{fe}/(m^2.year)$) of the pre-1975 dwelling stock have decreased by 40 % during the 1975–2009 period. Considering only thermal efficiency improvement (calculated as evolution of EPC Space Heating consumptions, $kWh_{fe}/(m^2.year)$), these unitary consumptions should have decreased by 54 %. Two main reasons can explain this gap: the well known "rebound effect" and the retrofitting discrepancy. During the same period, we have calculated that the increase of comfort (estimated as the increase of Space Heating Intensity Factor calculated for 6 dwelling segments) has been very limited (0.44 by 1975 to 0.50 by 2009: +14 %). This small increase is very close to the theoretical increase of Space Heating consumptions due to the increase of internal temperature in French dwelling (assumption: +2 °C). Our conclusion is that the majority of increase of Space Heating energy efficiency has been transformed in decrease of Space Heating consumptions. Rebound effect remained limited.

The ratio between observed Space Heating consumptions and normative ones (EPC calculation) for the pre-1975 dwelling stock by year 2009 is important (0.50). This enormous gap is usually considered as a promise of important future rebound effect. Our calculations show that this original important gap has not generated large rebound effect. The energy price ef-

Table 2. Pre-1975 dwelling stock EPC SH consumptions (6 segments) by 1975 and 2009 (source: authors' calculations).

	1975	2009	2009 / 1975
	pre-1975 dwelling stock		
	EPC SH calculations: kWhfe/(m².year)		2009/1975 ratio
SFH gas	575	287	0,50
SFH oil	608	320	0,53
SFH wood	1638	543	0,33
SFH electricity	248	144	0,58
MFH gas	458	276	0,60
MFH electricity	218	188	0,86
all SFH	653	288	0,44
all MFH	388	248	0,64
average value 6 segments	604	279	0,46

Table 3. pre-1975 dwelling stock SHIF (6 segments) by 1975 and 2009.

	1975	2009	2009 / 1975
	Space Heating Intensity Factors		2009/1975 ratio
	pre-1975 dwellings		
SFH gas	0,45	0,54	1,20
SFH oil	0,48	0,48	1,00
SFH wood	0,21	0,41	1,94
SFH electricity	0,59	0,60	1,01
MFH gas	0,30	0,42	1,39
MFH electricity	0,35	0,40	1,14
all SFH	0,46	0,52	1,12
all MFH	0,31	0,41	1,31
average value 6 segments	0,44	0,50	1,14

Table 4. Comparison of merit order (6 segments) for evolution of energy efficiency and comfort between 1975 and 2009.

	Merit order	
	Increase of Energy efficiency	Increase of comfort
	EPC calculations	Space Heating Intensity Factors
	pre-1975 dwellings	
1	SFH wood	SFH wood
2	SFH gas	MFH gas
3	SFH oil	SFH gas
4	SFH electricity	MFH electricity
5	MFH gas	SFH electricity
6	MFH electricity	SFH oil

fect and the important size of single houses (generating more important energy bills than apartments) have limited the phenomena. We consider that this ratio is more representative of the difference between "normative households' behaviour" (the one considered in normative calculation) and current one than of an image of future rebound effect. Today, and for the whole dwelling stock (pre and post-1975), this ratio is still important (0.62). In the future, if households do not change their comfort habits at an higher rate than during the last four decades, rebound effect will be limited and the ratio between observed Space Heating consumptions and normative ones (EPC calculation) will remain important.

But, even without taking into account rebound effect and retrofitting discrepancy, our calculations show that 2020 Grenelle's target cannot be reached if the retrofitting of existing dwellings is conducted in a Business As Usual way and at the same pace than during the previous 40 ones.

Glossary

BAU	Business As Usual
DHW	Domestic Hot Water
EPC	Energy Performance Certificate
EU	European Union
final energy	delivered energy (fe)
HVAC	Heating, Ventilation, Air Conditioning
kWh_{fe}	final (or delivered) energy measured by the property meter kWh

MFH	Multi Family Houses
PR	Primary Residences (1 household = 1 PR)
SH	Space Heating
SFH	Single Houses
SHIF	Space Heating Intensity Factor: Ratio between space heating current and calculated (theoretical) consumption

References

ADEME, 2013: Chiffres clés du bâtiment, p. 43.

ADEME, 2014: ADEME France Comté, Prix de l'énergie pour les utilisateurs – secteur de l'habitat – de 1973 à 2013, 2014.

Allibe, B., 2010, "Norm vs observations of residential space heating energy consumptions: Analysis of a gap and its consequences for long-term simulation", oral presentation at the EURO XXIV Conference, 2010, July 13, Lisbon, Portugal.

Cayla J-M., Allibe B., Laurent M-H., 2010, From practices to behaviours: Estimating the impact of household behaviour on space heating energy consumption, ACEEE 2010, 15–20 August 2010, Pacific Grove – USA.

CEREN 2010, 2012: Annual French dwelling stock data reports and surveys.

Devalière, I., Briand, P., 2011, La précarité énergétique : avoir froid ou dépenser trop pour se chauffer. INSEE premiere, n° 1351.

Laurent, M.H. and al, 2011, Energy efficiency for all! How an innovative conditional subsidy on refurbishment could lead to enhanced access to efficient technologies. eceee 2011.

Laurent, M.H. and al, 2013, Back to reality: How domestic energy efficiency policies in four European countries can be improved by using empirical data instead of normative calculation. eceee 2013.

Giraudet, L.G., 2011: PhD report: Les instruments économiques de maîtrise de l'énergie: une évaluation multidimensionnelle.

Grenelle, 2008: articles 4 et 5, LOI n° 2009–967 du 3 août 2009 de programmation relative à la mise en œuvre du Grenelle de l'environnement.

Palmer, J., Cooper, I., 2012, United Kingdom housing energy fact file. Dpt of Energy and Climate Change.

Pouget, A., 1989, Les réglementations françaises pour l'habitat et le secteur non résidentiel neuf", in: R.Dehausse, Energétique des bâtiments, Tome 3, Paris, PYC Edition, 1989.

Raynaud, M., 2014, Evaluation ex-post de l'efficacité énergétique des solutions de rénovation énergétique en résidentiel, PhD, Mines Paris Tech, 2014.

Sunikka-Blank, M. and Galvin, R. (2012) Introducing the prebound effect: the gap between performance and actual energy consumption, Building Research and Information, 40: 260–273.

Traisnel, J.P., 2001, Habitat et développement durable, Cahier du CLIP, April 2001.

EU 2006: European Union Energy Efficiency Directive (2006, revised 2013).