Energy renovation of poorly efficient French dwellings: does it help to reduce costs for the French health system?

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ABSTRACT

Among non-energy impacts of energy efficiency, financial savings on health systems are important (IEA, 2014).

This study compares the cost of retrofitting French inefficient dwellings and the financial savings on the health system. It has been conducted by a multidisciplinary and trans-channel team thanks to the adaptation of an English methodology (BRE, 2010) using the Housing Health and Safety Rating System (HHSRS) (ODPM, 2006) adapted to the French context.

This method evaluates the risk of *"exposure to low temperatures"* and the relationship between energy efficiency of housing and the likelihood of this risk for occupants. For various reasons, it has not been possible to quantify this relationship in France so far. However, we can assume that French people develop the same outcomes as the English if living with the same conditions.

Energy efficiency of the French dwellings stock was evaluated thanks to the national survey PHEBUS (CGDD, 2015). The method developed in this study showed that 13% of the French dwelling stock could be deemed "inefficient". The estimation of annual medical cost that could result from these energy inefficient dwellings for the health system is based on French health insurance databases (National claims database, 2007-2011). The impact of the households' income occupying these inefficient dwellings was quantified.

Three scenarios for the energy renovation of the inefficient dwellings stock were studied. The target was to renovate each inefficient dwelling in order to reach the average efficiency level of the whole 2012 French dwelling stock. The corresponding financial investment and the cost for the health system after renovation were calculated.

Annualized retrofit investment costs and annual financial savings to the health system were compared. Despite the fact that potential savings of energy were not taken into account, results show that, on average, financial savings on health system represent a significant part of the renovation investment. For the poorest households living in inefficient dwellings, the financial savings exceed the retrofit investment.

This study gives an example of an energy efficiency policy that can be financially justified without taking into account potential rewards due to energy savings.

Introduction

Health benefit of housing thermal retrofitting is identified as one of most important non-energy benefits of housing energy efficiency improvement (IEA, 2014). Specific studies - focused on this subject - exist, but a few part of them includes a quantitative evaluation of non-energy benefits.

This paper proposes an evaluation of the financial impact on the French health system of the improvement of space heating efficiency (building envelope thermal insulation and space heating equipment) of the poorest efficient housing of the French dwelling stock.

For that purpose, the adaptation of an English methodology to the French context was necessary.

Health risks related to thermal discomfort

Thermal discomfort is not only a question of comfort… but a question of health. The border between thermal comfort and good sanitary conditions have been established by numerous medical studies. There is a potential threat to health when the temperature falls below 18°C or rises above 24°C for a period of time. This range is based on the World Health Organization's guidance on thermal comfort for the home environment, which is aimed at protecting health, particularly the health of those most susceptible to low or high temperatures (Ormandy & Ezratty, 2012).

A national survey (see Figure 1) showed that a significant part of French households declare leaving with low indoor temperatures in their housing rooms. Such levels of indoor temperature can be responsible of medical outcomes that can be serious. Improving these temperatures when retrofitting these dwellings is useful for their occupants' health.

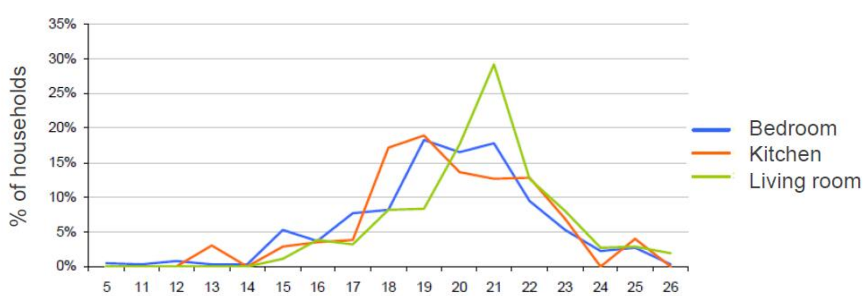

Figure 1. Distribution of indoor temperatures adopted by French households. *Source:* CGDD, 2013.

The English context and the HHSRS method

One of main priorities of public policies in United Kingdom is the eradication of fuel poverty and unsanitary housing. Both are linked and UK public authorities defined a category of housing as able to "seriously damage health". If occupants are able to prove that they are living in such a housing category, retrofitting of the housing is mandatory and the homeowner has the obligation to assume it.

The question of identifying the housing eligible to this category was asked. It was necessary to define quantified indicators. The adopted method in United Kingdom is the Housing Health Safety Rating System (HHSRS). It is an evidence-based method, developed in England over 10 years by the University of Warwick, and supported by the UK Building Research Establishment, and the London School of Hygiene and Tropical medicine. It was incorporated into the legislation in 2006 and used on a daily basis throughout England and Wales (ODPM, 2006; BRE, 2010). HHSRS was adopted in 2010 by the US Department for Housing and Urban Development as the Health Homes Safety Rating System. Among the

29 potential hazards identified by the HHSRS, there is *"exposure to low indoor temperatures"* ("excess cold"). We have studied this specific hazard and its impact on the health system.

HHSRS gives possible health outcomes for each hazard. These outcomes are categorized in four classes of harm based on degree of incapacity. A cost for the English health system can be calculated for each outcome (for more information see Ezratty et al, 2017).

The link between the category of housing and the generated health costs is quantified thanks to the English Housing Condition Survey (now replaced by the EHS). Data on housing conditions collected during three consecutive years on 40,000 dwellings was matched with health data to calculate the likelihood of a hazardous occurrence and of possible outcomes (harms) on the health system. This was made possible because of the existence of the UK Post Code System, each containing, on average, only 14 dwellings. Using the Post Codes, the three elements were matched, so allowing health outcomes (including those relevant to exposure to low temperatures) to be associated with the particular housing conditions (for these purposes, energy inefficiency), and with the household characteristics (in particular, whether it included a member of the age group vulnerable to low temperatures).

How to identify inefficient housing?

The HHSRS method relies on the rating of the housing condition established with data from the EHS. EHS is an annual survey (England and Wales) describing the housing condition of the dwelling stock. The energy efficient of housing is one of the *conditions* that are described in the survey. The method attributes an energy efficiency rating based on the thermal calculation method called SAP. The theoretical energy consumption of 5 energy end uses is calculated: space heating, domestic hot water, air conditioning (if housing is equipped), lighting and consumption of motors of mechanical ventilation (if housing is equipped). For this calculation, assumptions are made for the climate rigor (average national climate) and occupants' behaviour (normative scenario of desired indoor temperatures). The normative consumptions that are calculated at expressed at the final energy level (energy delivered to the end-user). Consequently, the perimeter of the calculation is the dwelling itself and the normative consumption can be assumed as a proxy of the energy efficiency of the dwelling (level of thermal insulation and efficiency of the 5 equipment corresponding to the 5 evaluated end uses).

The normative consumption is given per living m² in order to avoid that large houses should be low rated even when correctly insulated and equipped with high efficient equipment. The normative consumption is not a proxy of real consumption of housing, but a proxy of energy efficiency of housing.

As a first step, the SAP calculation gives a normative consumption expressed in kWh/m² (final energy). The highest is the consumption, the poorest is the efficiency. In order to give a rating value increasing with efficiency, EHS efficiency indicator uses a reverse (and normalized) scale expressed from 1 to 100. The worst efficiency of the dwelling stock evaluated with EHS (2012 survey) is the lowest value. With this normalized scale, the rating is increasing with the efficiency. 7 efficiency bands are defined (see Table 1).

Table 1. The EHS efficiency indicator bands (based on SAP)

EHCS efficiency indicator rating	Band
92 to 100	A
81 to 91	B
69 to 80	C
55 to 68	D
39 to 54	E
21 to 38	F
1 to 20	G

These last steps of the EHS efficiency indicator calculation process is completely similar to the process for the Energy Performance Certificate (EPC) calculation in United Kingdom. Unlike most of European countries, in UK, EPC is based on final energy consumption translated in energy bill and expressed on a normalized scale from 1 to 100, with 7 bands. EPC is based on the same SAP calculation than EHS efficiency indicator. The difference are at the very final step of the process: EPC is expressed as an annual normative bill (£) and normative annual Green House Gas emissions; and EHS efficiency indicator is based on normative final energy consumption.

This is the reason why there is a very often confusion between EPC and the EHS efficiency indicator especially since EHS efficiency indicator have no specific name…

Usually, if the value of the EHS efficiency indicator is 50, it is called “SAP 50”.

What likelihoods for what inefficiency?

For the risk “exposure to excess cold”, an individual is considered as exposed to low indoor temperature if living in a dwelling with SAP≤38 (bands F and G of the EHCS efficiency indicator). For this specific risk, HHSRS method gives a likelihood of an individual suffering harm over a twelve-months period of 1 in 18: 1 harmful event for every 18 energy inefficient dwellings (those with a SAP≤38).

Severity of outcome would vary, but would be one of the four classes of harm given in Table 2.

Table 2. Classes of harms for “exposure to low indoor temperature” risk in HHSRS method (based on pre-2000 data)

Class of harm	Spread of harm
I (extreme)	34%
II (severe)	6%
III (serious)	18%
IV (moderate)	42%

Adapting the HHSRS method to the French context

The French health system is very different from the UK one. For example, a patient can choose his doctor on the whole French territory. In particular, the organization of the French health system doesn’t make it possible to conduct a method similar to the HHSRS in France.

In order to adapt the HHSRS to the French context, we assume that an individual exposed to the same indoor conditions will have the same probabilities of developing the same diseases. We will apply the English likelihoods to French individuals.

We have to determine how many French dwellings are *“under SAP 38”.* To do this, we need to define a French indicator equivalent to the EHS energy efficiency indicator. In order to avoid confusion between the French indicator equivalent to the EHS energy efficiency indicator and English EPC or EHS energy indicator, we called Housing Energy Performance Indicator (HEPI) the French indicator equivalent to EHS energy indicator. Consequently, if the value of the French efficiency indicator is 50, it is called “HEPI 50”.

For the rating of the energy efficiency of the French dwelling stock, there is no continuous annual equivalent as EHS. The French survey Phebus (Performance de l’Habitat, Equipements, Besoins et UsageS de l’énergie) is the only public survey that was conducted on a representative panel of 2,389 French households; including an evaluation of the energy efficiency of the dwellings. The PHEBUS survey was carried out in 2012 by the Statistical Office (SOeS) of the French ministry for Environment, Energy and Sea (CGDD, 2015). For each dwelling, an evaluation of the DPE (Diagnostic de Performance Energétique, the

French EPC) have been conducted. The survey provides all the data that are necessary for the DPE calculation.

For our study, it appears that a few % of data on the 2,389 French households described in Phebus survey are not available (missing or inconsistent). As a result, the study is conducted on a panel equivalent to 26.3 million households instead of 28 million (6% less). Consequently, all our results must be multiplied by 1.064 in order to be equivalent to a 28 million households stock (occupied French dwellings stock for year 2012).

Due to differences between the French DPE and EHS energy efficiency indicator (see Table 3), additional calculations are needed.

Table 3. Comparison between EHS energy efficiency indicator and French DPE

	EHS energy efficiency indicator	French DPE
Energy level	Final energy	Primary energy
Presentation	Normalized scale 1 to 100 (very inefficient to efficient), 7 bands	Absolute values: < 50 kWh/m².year to > 450 kWh/m²/year, 7 bands
End uses	5 : space heating, hot water, lighting, mechanical ventilation (if equipped) and air-conditioning (if equipped)	3 : Space heating, hot water, and air-conditioning (if equipped)
Climate	national	local

In order to calculate a French EHS energy efficiency indicator, we have completed the data of the French DPE calculation:

- Calculation of DPE normative consumption for space heating, domestic hot water and air conditioning (when equipped) expressed in final energy,
- Addition of lighting consumption expressed in final energy (3 kWh/year.m²),
- Addition of motors of mechanical ventilation normative consumption (when equipped), expressed in final energy. Values based on normative consumption of French regulations for new dwellings (see Table 4).

Table 4. Normative consumption for mechanical ventilation calculation

	kWh/m².year (final energy)	
	Single family house	Multifamily house
Mechanical ventilation (single), hygro A and B	1.18	1.33
Mechanical ventilation (double) with heat exchanger	2.76	3.10
Mechanical ventilation (double) no heat exchanger	2.21	2.48
Mechanical ventilation ((auto adaptive)	2.76	3.10
Mechanical ventilation (insufflation)	2.76	3.10
Mechanical extraction on existing duct	3.31	3.72
Hybrid mechanical ventilation	0.86	1.48
Canadian well	1.18	1.33
Natural ventilation	0	0

The total normative consumptions obtained with this calculation are described in Figure 2 (left). In order to avoid very extreme values, and as it is currently operated in medical statistical studies, the 3% highest consumptions are levelled to the immediate lower value (see Figure 2, right).

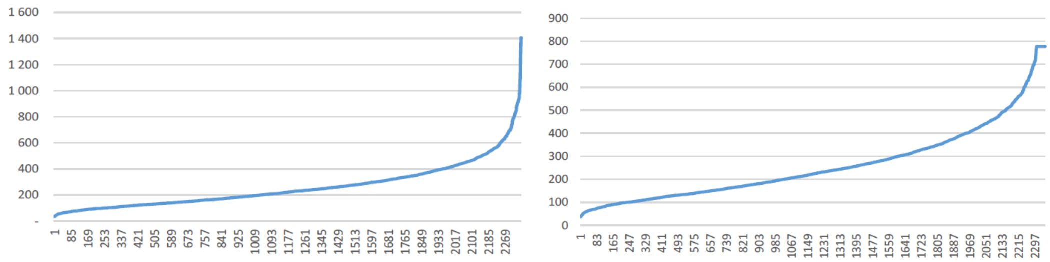

Figure 2. Left: Distribution of total normative consumption (kWh/m².year, Y axis) for each dwelling of Phebus panel (identified with its id number, X axis): all values; Right: with 3% levelled values.

The following step of the process is the expression of the normative consumptions on a normalized scale from 1 to 100 (see Figure 3, left). The correspondence between the HEPI indicator and the normative consumptions (final energy) for the 5 considered end uses is given in Figure 3 (left).

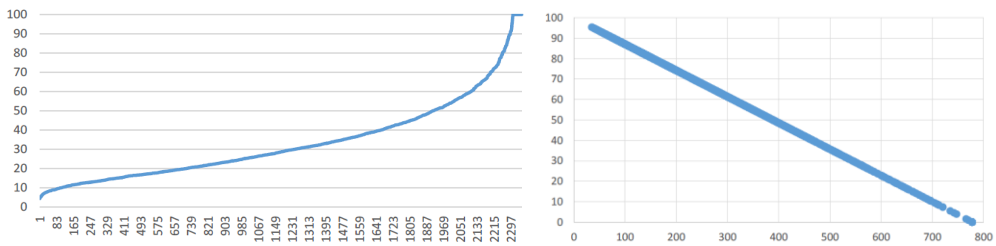

Figure 3. Left: Distribution of HEPI values (0-100, Y axis) for each dwelling of Phebus panel (identified with its id number, X axis): all values; Right: Correspondence between HEPI values (0-100, Y axis) and the normative consumptions (kWh/m².year, final energy, 5 end uses, X axis)

An image of the French dwelling stock rated with the HEPI indicator is given in Figure 4. The average value of the HEPI indicator for French dwelling stock is 62.5. The average normative consumption for the 5 considered end uses is 284 kWh/m².year (final energy). For the same year (2013), the observed consumption for the same 5 end uses was 144 kWh/m².year (CEREN, 2014). This “factor 2” ratio observed between normative and “real” consumptions is mainly due to space heating and domestic hot water consumption and is closed to ratio calculated between DPE normative consumptions and real ones for space heating (Allibe, 2010).

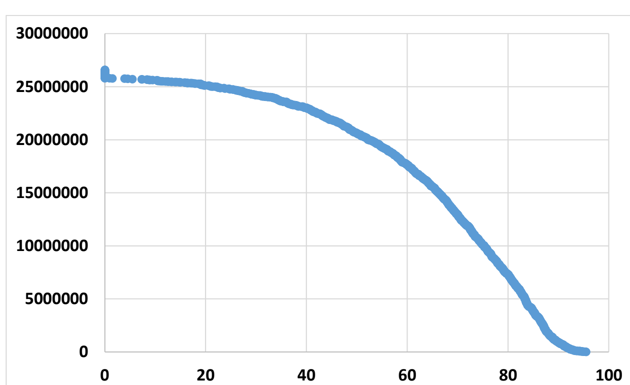

Figure 4. Cumulated population of French dwellings stock (Y axis) vs HEPI indicator (0-100, X axis)

The last step of the process is the definition of a threshold equivalent to SAP 38 for the French dwelling stock.

After several tests, it appears that the same threshold than UK is relevant for the French dwelling stock rated with HEPI indicator. The HEPI 38 threshold is equivalent to a normative consumption for the 5 considered end uses of 477 kWh/m².year (final energy). It is 1.68 factor more than the average value of the whole stock.

13% of the French housing (3.47 million) are rated with an HEPI indicator under 38. This is very close to the UK situation. For the following part of this study, we will call these inefficient dwellings as "under HEPI 38".

Describing the inefficient French dwelling stock

Almost 3.5 million of French dwellings are under HEPI 38. Their average HEPI value is very low (16.3). The corresponding normative consumption for the 5 considered end uses is 650 kWh/m².year (final energy). This 2.3 factor more than the average value for the whole stock! Figure 5 compares the characteristics of the whole French dwelling stock and the inefficient one. Dwellings under HEPI 38 are mainly single family houses, own occupied and aged ones. Space heating fuel is mainly gas and oil, electricity is very little.

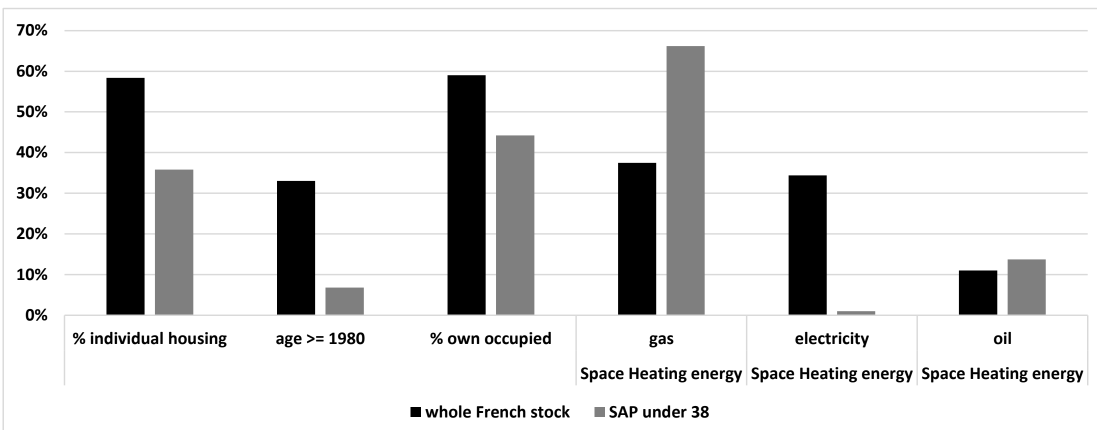

Figure 4. Comparison of French dwelling stock: whole and inefficient (under HEPI 38)

These characteristics are significantly different of those of the dwelling population rated in F and G bands with French DPE. This population have been described with the same Phebus survey data than our calculation (CGDD, 2014). The dwelling population size is twice (7 to 8.5 million depending on the source). The main reason is that the French DPE is expressed at the primary energy level. This is a conventional factor calculated from final energy consumptions: electricity consumptions are multiplied by PEF 2.6 (Primary Energy factor[1]) and fossil consumptions (including biomass) are multiplied by PEF 1.

[1] Primary Energy Factor (PEF) is a conventional coefficient used in order to compare energy consumptions at the primary level. The energy supply chain has 3 levels: primary, final and useful. The primary level gives consumptions of rough energies (primary energies) before any transformation. The final level is the energy consumption when delivered (final end user). The useful energy is the theoretical energy consumption necessary for a given energy service. The ratio between useful and final energy consumption is the efficiency of the equipment delivering the energy service. The ratio between primary and final energy consumption is the PEF. As electricity is a secondary energy, PEF for electricity are higher than for fossils. Its value depends of the national electric mix and necessitates conventional choices. In France, PEF for electricity is 2.58 and 1 for other energies (including biomass).

Consequently, 3.7 million dwellings heated with electricity are rated F or G with French DPE (44% of French DPE F and G bands). These electric fueled dwellings are not under HEPI 38 because the EHS energy efficiency indicator is expressed in final energy. Its value depends of the efficiency of the building envelope and of the equipment (mainly space heating and domestic hot water) and not of the efficiency of the considered energy supply chain.

In France, on an average, dwellings heated with electricity have a better thermal insulation than dwellings heated with fossils (see Figure 5 for single family houses stock). The efficiency of electric equipment for space heating are higher than those fueled with fossil energies (1 for direct electric heating and 2 to 3 for Heat Pumps). For domestic hot water, the efficiency of equipment fueled with electricity or with fossils are closed (excepted for Heat Pumps dedicated to domestic hot water that have a better efficiency).

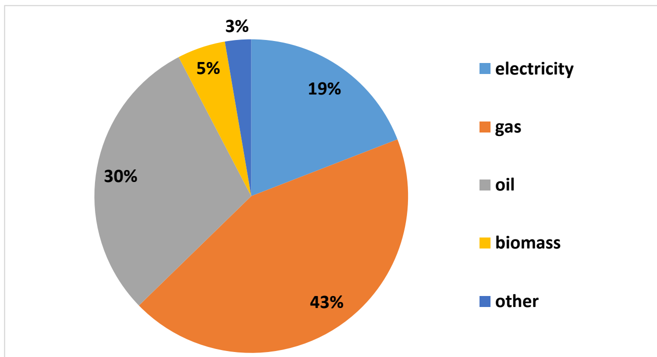

Figure 5. French non insulated single family dwelling stock: 1.3 million (distribution vs space heating fuel, source: authors' calculation from Phebus survey data)

The EHS energy efficiency is expressed at the final energy level. Consequently, our HEPI indicator is also expressed at the final energy level. It takes into account the efficiency of the dwelling itself (envelope and equipment of the 5 considered end uses). Due to their better efficiency if expressed at final step, on an average, dwellings heated with electricity have a better rating than those fueled with other energies.

We recalculated the proportion of dwellings heated by electricity if the HEPI indicator had been expressed at primary energy level (multiplying electricity consumption by PEF factor 2.6). Electrically heated dwellings would have accounted for 15% of the total. It is still less than the 44% of dwellings heated with electricity in French DPE F and G bands. This seems to be due to the fact that the DPE is an indicator expressed in absolute values and not a relative indicator like the EHS energy efficiency factor. The English factor captures the worst dwellings, not the ones beyond an absolute threshold.

Retrofitting the French dwelling stock under HEPI 38

We have considered retrofitting scenarios leading to inefficient housing stock before renovation at a level of performance at least equal to the average of the current dwelling stock. That means that the value of HEPI factor of these inefficient dwellings must be changed from 650 kWh/m².year (SAP 16.3) on an average for the inefficient dwelling stock; to at least 284 kWh/m².year (-44%) for all current inefficient dwellings.

We calculated different retrofitting scenarios based on 7 unitary retrofitting actions (see table 5): replacement of space heating and domestic hot water equipment, thermal insulation of the dwelling envelope, installation of a mechanical ventilation. Depending of each inefficient dwelling of the Phebus data base, only one or a combination of several unitary retrofitting actions is necessary in order to reach at least HEPI 62.5 for each renovated dwelling.

Table 5. Unitary retrofitting actions considered in retrofitting scenarios

	Unitary action
1	Replacement of space heating equipment with the same (new) equipment
2	Walls thermal insulation
3	Roof thermal insulation
4	Single glazing replaced with double glazing
5	Floor thermal insulation
6	Installation of mechanical ventilation
7	Replacement of space heating equipment with Heat Pumps

3 retrofitting scenarios are considered:

- Scenario 1 favors the identical replacement of heating equipment supplemented by the actions of thermal renovation of the building envelope (that are often necessary in scenario 1).
- Scenario 2 generalizes the replacement of heating equipment with Heat Pumps. As scenario 1, this action is supplemented by the actions of thermal renovation of the building envelope. However, this supplementations is quite rare in scenario 2.
- Scenario 3 is a mix of scenarios 1 and 2. It favors the 2 main heating energies (gas and electricity). This action is supplemented by the actions of thermal renovation of the building envelope (more often than in scenario 1).

Based on unitary retrofitting actions (see figure 6), the investment cost associated to each scenario was calculated. In all scenarios, all heating equipment is changed. For this action, we only count the first investment as this action is considered as a fatal investment. Our scenarios are transition scenarios, not scenarios to date. After the first investment in a new efficient heating equipment, this equipment will be renewed in the future, but the corresponding investment of the renewal is not counted. Same philosophy for envelope thermal insulation actions: if this kind of action is required, we count the first investment only.

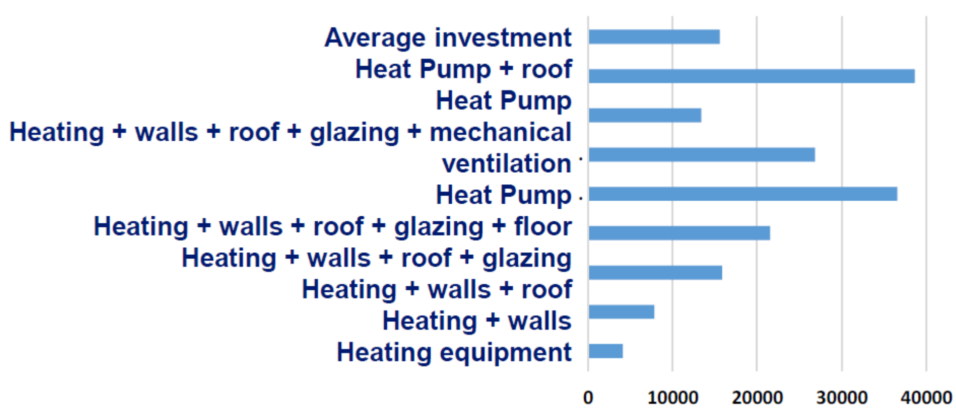

Figure 6. Investment costs for packs of unitary retrofitting actions (equipment + installation, € ex VAT, based on costs/m², source: Osso et al. 2017)

In order to compare the cost of retrofitting programs to the financial savings in the French health system, an annual based comparison is necessary. For each scenario, the average life span of the combination of all unitary actions is calculated. This calculation is based on unitary actions life pans (see Table 6) and number of each unitary action, depending of the scenario. The total investment cost of the scenario is divided by the average life span of the scenario's unitary actions. This is a difference with the UK method where the total investment cost of the scenario is divided by the average payback time of the scenario's unitary actions. After discussion, we have chosen not to use pay back times as they are calculated with normative consumptions. As we saw earlier in the paper, the normative consumptions are twice as high as the actual consumptions. The reason is that SAP calculation in UK (or DPE calculation in France) is made in order to evaluate the energy efficiency level of a house, not its energy consumption. As a result, pay back times that are calculated with normative consumptions are very short and unrealistic. Dividing the total investment costs by normative payback time leads to very high annual investment costs; and at the end of the normative payback time, the investment will not be replaced as it is under its lifespan. This is the reason why we have chosen to use the average life span instead of payback time.

The 3 scenarios are compared in Table 6. Scenario 2 gives the best energy efficiency after retrofitting. Its HEPI energy efficiency factor (HEPI 88) is higher than the current whole dwelling stock's one before retrofitting. Scenario 3 is based on the generalization of Heat Pumps. It explains whys it is the most efficient, but the one with the highest annual investment costs. The high efficiency of Heat Pumps makes that the scenario 2 necessitates less thermal insulation actions than scenarios 1 and 3. Consequently, the majority of the unitary actions of the scenario 3 is the replacement of heating equipment. Heating equipment have shorter lifespan than thermal insulation actions' lifespans. The total investment cost is close to the other scenarios' ones, but, due to shorter average lifespan, the annual investment cost is higher. We chose scenario 3 as the best compromise between efficiency after retrofitting and annual investment cost.

Table 6. Main results for the 3 retrofitting scenarios

	Whole dwelling stock	French dwelling stock under HEPI 38			
	Before retrofitting	Before retrofitting	After retrofitting		
			Scenario 1	Scenario 2	Scenario 3
EHCS energy efficiency indicator	63.5	16.3	72	81	73
kWh/m².year (normative consumption, 5 end uses, final energy)	284	650	219	144	210
Energy bill (€/dwelling.year, VAT included) *(*)*	/	/	1148 €/year	1209 €/year	1187 €/year
Average lifespan (years)	/	/	23.9 years	15.7 years	22.7 years
Total investments (billion €, ex VAT)	/	/	51	51	46.5
Annual investment (billion €/year)	/	/	2.13	3.25	2.05

(*) theoretical bill for only 2 end uses (space heating and domestic hot water), excluded subscription cost

The average retrofitting cost per renovated dwelling in scenario 3 is 13,400 €/dwelling (ex VAT). It is higher than the average investment in energy efficiency made by French households when they renovate their dwelling. The OPEN survey, conducted by ADEME in 2015, gives an average of 10,000 € (VAT included) for an average complete renovation conducted on a 3 years period (source: OPEN, 2016). It is very low compared to the program “Je rénove BBC” conducted in French Alsace region. This program had the ambition to renovate housing up to a very higher level of energy efficiency compared to scenario 3 (low consumption level). Consequently, the average cost of renovation was 68,000 € (ex VAT) in “Je rénove BBC” program (source: CEREMA, 2017).

What financial savings for the French health system?

The 4 classes of harms for “exposure to low indoor temperature” risk described in HHSRS method have been updated and adapted to the French context in order to provide relevant standard costs for each class of harm (see Table 7). Costs are adapted from French Health Insurance data (AM, 2016).

Table 7. Classes of harms for risk “exposure to low indoor temperature” adapted to French context

Class of harm	Outcome (England)	Outcome (France)	French Health System Cost
I (extreme)	Heart attack leading to death, after some time	Acute coronary syndrome leading to death	9,863€
II (severe)	Heart attack	Non-fatal episode of Acute Coronary Syndrome	13,850€
III (serious)	Respiratory condition	Severe lower respiratory tract infection with hospitalization	2,138€
IV (moderate)	Occasional mild pneumonia	Mild to moderate pneumonia (outpatient care)	53€

Using the HHSRS method, over the entire French dwelling stock, the likelihood is 1/109. For dwellings rated better thanHEPI 38 (> HEPI 38), the probability falls to 1/380. On the contrary, for dwellings rated lower than HEPI 38 (≤ HEPI 38), the likelihood climbs to 1/18. There is on average 20 times more chances to develop "excess cold" health events in housing under or over HEPI 38.

Renovating all French dwelling stock under HEPI 38 to the efficiency of the current French dwelling stock generates an economy of 634 million €/year on the French Health system. This is 31% of the annual necessary cost for the retrofitting.

Sensitivity to occupants poverty

Thanks to HHSRS method, it is possible to calculate the risk depending on the poverty of dwellings’ occupants. The risk is increasing when poverty increases (see Table 8):

- The poorest households (deciles of income 1,2,3) living in dwellings under HEPI 38 are 1,284 million (38% of dwellings ≤ HEPI 38). On an average, the probability that the dwelling they occupy generates "excess cold" health costs is 1/7.
- The poorest of the poorest (deciles of income 1,2,3, and below poverty threshold (< 60% median income)) are 0.608 million (18% of dwellings ≤ HEPI 38). On an average, the probability that the dwelling they occupy generates "excess cold" health costs is 1/4.

The economy generated to the French Health system when renovating a dwelling under HEPI 38 occupied by the poorest households is higher than the economy generated by the retrofitting of an average dwelling under HEPI 38 (see Table 8):

- For the poorest households, the generated economy reaches 90% of the annual cost of retrofitting,
- For the poorest of the poorest, the generated economy is 60% higher than the annual cost of retrofitting.

Table 8. Households leaving in dwellings under HEPI 38 characteristics

	Dwellings < HEPI 38		
	Whole population under HEPI 38	Households with deciles of income 1,2,3)	
		Whole HH deciles 1,2,3	Households below poverty threshold
Household population (million)	3.47	1.284	0.608
% of population under HEPI 38	100%	38%	18%
Likelihood	1/18	1/7	1/4
Economy (million €/year)	639	617	504
% of annual retrofitting costs covered with health economies	31%	90%	160%

Comparing with other studies

Varied estimations have been established, relying on different methods. Using HHSRS approach, the UK Building Research Establishment (BRE) estimated £600 million each year potential savings to the English National Health Service (BRE, 2010). In 2016, Eurofound adapted the HHSRS/BRE model and estimated the cost savings to the health sector achieved by remedying housing inadequacies for 28 European countries. Savings estimated for France were 930 million/year. Eurofound concluded that annual savings in the health system accounted for 2/3 of investments in housing risk reduction (Eurofound, 2016). In 2017, the collective "Rénovons" has estimated €758 million per year the gains for the health system of the renovation of 7.4 million French homes deemed non-performing (Rénovons, 2017). Despite the fact that not all of these studies were conducted using the same methodology as our study, they find results similar to ours in terms of savings for the French health system.

Conclusion

The study shows that it is possible to adapt the English HHSRS method to the French context. We find results close to other studies while relying on a proven approach and whose steps are transparent.

In the context of a "medium" ambition energy renovation, the financial gains generated on the French health system are at least 30% of the annual cost of the renovation program.

This rate turns out to be much higher if we can target the poorest households living in energy inefficient housing. It then climbs to 90% of the annual amount of the renovation program. It even exceeds it for even poorer households (below the poverty line) for which the savings are much higher than the annual costs.

These important benefits, however, can only be achieved if adapted indicators are used to target the dwellings most in need of renovation and to identify the poorest households living there. For energy-inefficient housing, the EHS indicator (or the equivalent that we have defined for France, HEPI) is relevant. For precarious households, the cross-fertilization of households' income levels and the non-performance of the housing they occupy can bring very significant social gains to households while achieving the highest savings per household for the health system.

Quantifying gains for the health system is a first step. Quantifying societal gains is, however, a much more complex one. What are the gains for the active, for the inactive and their caregivers, for today's schoolchildren, so for the assets of tomorrow? Even though it is complex, and there are several possible approaches, it seems clear that preventing exposure to low indoor temperatures has cost benefits for the individual, the society and the local and national economy.

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