**Assessment of health costs and costs benefits of housing energy improvement in France**

Véronique Ezratty[1], David Ormandy[2], Marie-Hélène Laurent[3], Fabienne Boutière[3], Anne Duburcq[4], Laurène Courouve[4], Pierre-André Cabanes[1]

1 SEM – Service des Etudes Médicales d'EDF (EDF Medical Research Department), Levallois-Perret, France
2 Warwick Medical School, University of Warwick, Coventry, United Kingdom
3 EDF R&D, Département TREE, Les Renardières, Moret sur Loing, France
4 Cemka-Eval, Bourg-La-Reine, France

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**Correspondence:**
Dr Véronique Ezratty
Service des Etudes Médicales d'EDF
45 rue Kleber
92309 Levallois-Perret Cedex
France
veronique.ezratty@edf.fr

**Abstract**

Health is an important but still insufficiently assessed aspect of energy-efficiency improvement programmes. The aim of this research project was to assess whether the cost of investment in the renovation of thermally inefficient housing in France could be offset by savings in health expenditure.

The research relies on English methodology based on the Housing Health and Safety Rating System (HHSRS) used to identify homes that pose a health risk. The comparison of data on housing with objective data on health (which is possible in England) enabled us to estimate the likelihood of the occurrence of effects harmful to health according to the risk of exposure to excessively low indoor temperatures, and then calculate the corresponding medical costs. Based on data from France's national Phébus survey and adopting the English approach to the assessment of housing energy efficiency, 3.5 million main homes – i.e. 13% of all main dwellings in France – were judged to be thermally inefficient. Adapted to the French context, health expenditure related to the energy inefficiency of housing was estimated and compared to renovation costs. Results suggest that investment in a suitable programme of energy-efficiency improvement would lead to savings for the health system that would be even greater for low-income households. For those households, the medical costs avoided would be of the same order as the renovation costs.

## Introduction

Home energy inefficiency increases the risk of exposure to excessively low indoor temperatures, which can have harmful impacts on the health of occupants, particularly in terms of cardiorespiratory and mental health [1, 2, 3]. These effects on health can result from more than 24 hours of exposure to temperatures below 18° C, the lower limit of the domestic thermal comfort range recommended by the World Health Organization (WHO) [4].

The implementation of home energy-efficiency improvement measures is complex and their high cost makes them unaffordable for most households, especially those on the lowest incomes. Moreover, renovation costs are not always offset by energy savings, which often turn out to be less than anticipated [5].

In England, studies carried out by the Building Research Establishment (BRE) has shown that improving the energy efficiency of inefficient housing has a beneficial effect on the health of occupants, with a positive cost-effectiveness ratio [6, 7]. The methodology developed by the BRE to assess this health cost benefit relied on the Housing Health and Safety Rating System (HHSRS), the official method of assessment of health risks linked to housing conditions, which is used in national surveys in England and Wales (English Housing Survey EHS) [8].

This methodology based on the HHSRS system was also used locally by other researchers to conduct cost-benefit analyses, for example in London [9] and Sheffield [10]. The European Foundation for living and working conditions (Eurofound) project examining the cost of substandard housing in 28 European countries also employed that methodology [11].

Other research has used different approaches, such as modelling to estimate the medical costs of energy inefficiency commissioned by the National Institute for health and Care Excellence (NICE) in England [12], or field assessment coupled with intervention in New Zealand [13]. In France, the 'Rénovons' (Let's Renovate) initiative evaluated the anticipated costs and benefits of the planned renovation of 'energy sieves' in the private sector by 2025. This research showed that the energy-efficiency improvement of these thermally inefficient homes could save the health system 758 million euros a year [14].

The objective of our study was to estimate medical costs related to energy inefficient housing and energy precariousness in France (adapting an HHSRS-based English methodology to the situation in France) and compare them to the costs of investment in thermal renovation.

The study only took into account direct medical costs related to the risk of exposure to low home temperatures. Medical costs attributable to the potential effects on health of other risks liable to be aggravated by low home temperatures – such as dampness and mould or domestic accidents – were not examined. Indeed, since factors other than excessive cold can result in these hazards, the perimeter of the research was established so as to avoid confusion. Also, the indirect potential costs to society, such as those related to absenteeism, unemployment and negative impacts on education or home-care services, were not included.

**Material and Methods**

So we used a methodology based on the HHSRS developed in England and adapted to the context of France. The method and its adaptation have previously been described in detail [15]. There will only be a reminder of a few principal approaches.

***The Housing and Health & Safety Rating System (HHSRS)*** [16]

In 1996, the UK government commissioned the University of Warwick to devise a new approach for the assessment of housing conditions [17]. After 10 years of development, the HHSRS was adopted into law as a method of assessing health risks related to housing conditions in England and Wales [18, 19]. The HHSRS is the official method used in the annual English Housing Survey (EHS). In 2010, the HHSRS was approved by the US Department for Housing and Urban Development [20]. The HHSRS was developed by stages: i) an in-depth review of literature on the relationship between housing and health which identified 29 potential risks related to housing conditions, including exposure to excessively low temperatures in the home (the only risk examined in this research); ii) the correlation of data on housing conditions with descriptive health data recorded in a specific database developed using information on visits to General Practitioners (GPs) and hospitals, which analysed the relationship between the two. Data on housing characteristics were collected by inspectors during technical visits for national surveys covering nearly 40,000 dwellings over three consecutive years. These data identified dwellings that posed a risk to health which was considered unacceptable according to the HHSRS.

For the risk of exposure to low home temperatures, the Standard Assessment Procedure (SAP) recommended by the UK government to measure the energy-efficiency and carbon-emission rates of dwellings was the chosen method for assessment [21]. The UK government judged that with an SAP score lower than or equal to 38[1], homes did not offer sufficient protection against the risk of exposure to low indoor temperatures (an unacceptable HHSRS risk) [22]. Indeed, indoor temperatures have not generally been measured in housing surveys, except for the one in 1991 that did so in a sub-sample of 16% of homes.

Health data was collected from a number of databases, including registers of hospital and A&E admissions, and visits to GPs. It was possible to correlate housing

[1] Initially, the threshold set by the BRE was SAP 35. However, the UK government then decided to change it to SAP 38, which corresponds to the upper limit of the EPC (Energy Performance Certificate) F rating.

and health data using the British postcode system[2]. That correlation provided an estimation of the likelihood of the occurrence of an effect harmful to health (a probability expressed as a ratio) over the following twelve months for each of the 29 risks identified. For the risk of exposure to excessively low indoor temperatures (one of those 29 risks), the probability was 1 in 18, meaning that a health event was expected in 18 thermally inefficient homes within 12 months. That calculation was based on the likelihood of the occurrence of a health event that could be related to exposure to low temperatures among persons living in thermally inefficient homes (SAP $\leq$ 38).

Once the likelihood of the occurrence of an effect harmful to health was known, it was necessary to characterise that event, which could range from major harm leading to death to moderate harm requiring management by a GP at least and so recorded. It was decided to arbitrarily categorise these health effects in four classes according to the degree of incapacity, enabling comparison of the different effects. For the risk of exposure to excessively low indoor temperatures, the effects ranged from death by myocardial infarction in class I (extreme impact) to a breathing disorder requiring a visit to the doctor but not hospitalisation in class IV (moderate impact) (Table 1). This categorisation by severity is presented as a percentage (a parameter called 'spread of harms'), which shows which of the four categories of impact is most likely to occur. Additional analyses of health data were later carried out by the London School of Hygiene & Tropical Medicine (LSHTM) to consolidate the assessment of these spreads of harms [23]. In particular, the results showed that the year of construction of the housing was a decisive factor in excess winter mortality, with a significant difference between housing built before 1980 and more recent homes, in which excess winter mortality was lower. That difference in risk could be attributed to the energy inefficiency of the housing.

For our research, the initial data of spread within each category of spread of harms originally recorded from 1996-1997 to 1999-2000 were adapted to reflect the major fall in myocardial-infarction mortality observed over the last 15 years [24] (Table 1).

Since the National Health Service could identify the costs of the diagnosis and treatment of illness and accidents, it was possible to estimate the medical cost related to each risk and calculate the medical costs resulting from substandard housing.

The English Housing Survey also included estimations of the cost of works intended to eliminate or reduce risks, which enabled an estimation of the cost-benefit ratio of renovation [6, 7]. Developed by the BRE, that approach inspired this project.

[2] In the UK, each postcode includes an average of 14 homes. Those homes generally have similar characteristics, having been built in the same period. For reasons of confidentiality, a health event cannot be linked to a precise address.

***Adapting the research to the situation in France***

It seemed reasonable to suppose that persons living in France and exposed to low indoor temperatures in their home would experience the same thermal discomfort and the same health impacts as those living in England. The methods of assessment of energy efficiency used in France and the United Kingdom have been detailed elsewhere and only the differences between them that enable an understanding of the approach taken in the research will be underlined (Table 2).

In the United Kingdom, this assessment (carried out in housing surveys using the SAP calculation method) quantified efficiency in terms of theoretical consumption of final energy per floor surface unit to produce a score on a scale of 0 (very inefficient) to 100 (extremely efficient). In France, the measurement of energy performance is based on the calculation of a 'Diagnostic de Performance Energétique' or DPE (Energy Performance Diagnosis) that represents theoretical primary-energy consumption for three purposes: heating, domestic hot water and air-conditioning [25]. The first task in this research was to correlate the English SAP and the French DPE. For the purposes of our research, we developed an energy performance indicator for France based on the indicator used in England, taking into account final energy related to five uses (heating, domestic hot water, lighting, air-conditioning and mechanical ventilation). This work was done in a number of stages. First, the theoretical consumption of heating was adjusted to take into account the indoor and outdoor temperature difference during the heating season in the district where the home was located, compared to the average national value – the average temperature over 30 years in degrees Celsius, Method 3CL-DPE v1.3, data from the CEREN (French National Centre for Economic Research and Energy Surveys). Then additional final-use consumption for lighting, air-conditioning and mechanical ventilation was calculated and included. Finally, a scale from 0 to 100 was chosen and inverted so that the higher the number, the greater the energy efficiency. To avoid any confusion, the term 'Indice de Performance Energétique du Logement' or IPEL (Housing Energy Performance Index), a French equivalent of SAP, was used. An IPEL of 38 was selected as the threshold below which homes were judged thermally inefficient. After sensitivity testing, it proved appropriate. This enabled the adoption of the equivalent of SAP 38 as the threshold to identify inefficient housing in France – in other words, homes providing insufficient protection against exposure to low indoor temperatures.

The research used data from the Phébus survey (Performance of Habitat, Equipment, Needs and Use of Energy)[3], which examined a representative sample of the 2012

[3] Phébus was a national survey on housing and energy carried out in 2013 by the French Ministry of the Environment (METDD) as part of the survey programme of the Conseil national de l'information statistique (Cnis – National Council for Statistical Information). In addition to interviews with the occupants of 5,405 homes that were representative of housing in Metropolitan France (28 million main dwellings in 2012), information on energy equipment and the behaviour of households was

housing stock of main residences in Metropolitan France: 28 million dwellings [26]. The analyses covered 26.3 million homes because in 6% of cases, the data were inconsistent or incomplete, and consequently could not be used. The households judged to be in a situation of energy insecurity were those whose income per unit of consumption was in the first three deciles[4], and who were occupying a thermally inefficient home. The poverty threshold used was the one determined by the European Commission – i.e. income below 60% of median household income [27]. Based on the Phébus survey database, 3.5 million (13%) main homes with an IPEL equal to or less than 38 were judged thermally inefficient and unable to protect occupants from exposure to low indoor temperatures (an unacceptable risk to health according to the HHSRS). Among the occupants of those inefficient homes, low-income households were potentially the most at risk because they would not be able to afford to heat their home to the temperature needed to protect their health. At least theoretically, the better-off households would have the means to maintain their thermal comfort (although they would be wasting energy), even if their dwelling is a potential threat to their health, especially if they are 65 or older [28, 29]. This hypothesis led to the extrapolation of different probabilities (likelihoods) of the occurrence of harmful effects on health for three different levels of income (Table 3). The direct medical costs used were those obtained from the databases of French National Health Insurance [30, 31] (Table 4).

The cost of renovation of thermally inefficient housing was assessed by an R&D team from EDF (Electricité de France) and has been detailed elsewhere [32, 33]. The stage involved calculating the cost of upgrading of thermally inefficient homes (IPEL ≤ 38) into homes as efficient as average residential housing in France (IPEL ≥ 63.5). This upgrade from an IPEL of ≤ 38 to an IPEL of ≥ 63.5 corresponds to a reduction of 56% of normative (theoretical) final consumption for the five conventional uses. Energy-efficiency improvement scenarios were considered: i) scenario 1 consisted of the renovation of heating and domestic hot water (DHW) equipment, which would continue to use the same energy and include thermal-insulation work on the building; ii) scenario 2 generalised the use of heat pumps with building work if needed (rare); iii) scenario 3 focused on the two main heating energies (gas and electricity) and included building work. The renovation programme for scenario 3 was judged the most advantageous. It resulted in a level of performance of 210 kWh

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collected. Data on theoretical energy performance was gathered for a subsample of 2,389 dwellings. Phébus also included information on subjective satisfaction in relation to heating.

[4] Data on income is often presented in the form of brackets of 10 % for households or individuals, which statisticians call ‘deciles’. A decile is not the bracket as a whole, but the value that separates one bracket of 10% from another. So the first of the deciles of income separates the 10% who are paid the least from the 90% who are paid the most. The second decile is the level of income for which 20% are paid less and 80% more. The third decile is the level of income for which 30% are paid less and 70% more.

of final energy/($m^2$ per year), i.e. an IPEL of 73 after renovation. It implied an investment of 47 billion euros for the stock analysed.

The investment was considered to be made fully in the first year of the programme and so no discount rate was applicable. Health costs would be avoided annually from the second year over a period of 22 years, for an identical amount. The research uses a collective viewpoint limited to direct costs, whatever the financing rate.

Sensitivity testing on variations of the different parameters and hypotheses previously described was conducted according to the recommendations of the HAS [34]. The variations tested for each of the parameters are presented in table 5. For each population studied, the univariate sensitivity analysis was described using a Tornado diagram. The multivariate probabilistic sensitivity analysis simultaneously took into account variations of all the parameters using a beta distribution for the IPEL and for the proportion of homes below the poverty threshold among those occupied by low-income households, and a normal distribution for the other parameters of the model. It produced a cost estimation based on 1,000 simulations.

## Results

### *Medical costs related to domestic energy inefficiency*

The average cost of medical treatment of a representative harmful health impact was estimated using the PMSI (Medical Programme Information System) database for each of the four categories of severity. On the bases of frequency of occurrence in each category of severity (spread of harms), the average 'theoretical' medical cost of an impact was estimated to be 3,318 euros (Table 4). The probability (likelihood) of the occurrence of a harmful health impact within 12 months being 1 in 18 for inefficient homes, the annual cost for the French health system that can be attributed to inefficient homes as a whole – i.e. 3,467,835 homes with an IPEL $\leq$ 38, was estimated to be 639 million euros. Similar calculations gave an estimation of the annual costs for different levels of income (Table 6). For the 1,284,267 inefficient homes occupied by households with an income by spending unit (SU) between deciles 1, 2 and 3, the annual medical costs were estimated to be 617 million euros. For the 608,069 inefficient homes occupied by households with an income by SU below the poverty threshold, the medical cost was estimated to be 504 million euros.

### *Sensitivity testing*

Sensitivity testing produced estimates very close to those of the main model devised. For the 3,467,835 inefficient homes (IPEL $\leq$ 38), sensitivity testing showed that neither variations in medical costs, nor spread over four categories of severity, nor the threshold chosen for the IPEL, nor the spread of harms, significantly modified the global estimate of medical costs. For example, an IPEL of 32 (the lower threshold) results in an annual medical cost of 524 million euros; on the contrary, an

IPEL of 43 (the higher threshold) results in an annual medical cost of 709 million euros. The multivariate probabilistic sensitivity analysis based on 1,000 simulations produced an estimated annual medical cost of 611 million euros (standard deviation of 93 million with the main model). The same type of sensitivity analysis of the 1,284,267 inefficient homes occupied by households with an income by SU in deciles 1 to 3 results in an estimated annual medical cost of 588 million euros (standard deviation of 92 million). Of the 608,069 inefficient homes occupied by households with an income by SU below the poverty threshold, the estimated annual medical cost is 476 million euros (standard variation of 80 million).

***Comparison of energy-efficiency improvement costs with the annual medical costs of thermally inefficient homes***

It was possible to make this comparison after i) annualisation with no discounting of the cost of investment in the improvement of the energy efficiency of inefficient homes according to the potential durability of each measure (from 15 years for replacement of the heating system to 30 years for roof insulation) (Table 7). The initial investment of 47 billion euros for the housing stock analysed corresponds to an annualised cost of 2 billion euros a year for 23 years (average durability of renovation work carried out in the chosen scenario) and an average renovation price pack of 13,400 euros per home, ii) assessment of the likelihood of the occurrence of a health event after renovation using the 'formula' of the HHSRS, which showed that the likelihood was 1/2,250 for the homes renovated (corresponding to an IPEL of 69-80) [35]. So it was possible to compare the annual renovation costs for inefficient homes (IPEL $\leq$ 38) with annual costs avoided for the health system, enabling calculation of the cost-benefit ratios (Table 8).

The results showed that for a renovation programme to upgrade the efficiency of the homes to the average level of French housing stock, the savings for the health system were even higher when the income of the households occupying the homes was low. For low-income households (income by SU in deciles 1, 2 or 3), the medical costs avoided each year were of the same order as the annual renovation costs. For the homes occupied by households under the poverty threshold, there was a profit, and each euro invested in energy-efficiency improvement provided savings of 1.65 euros in health expenditure.

## Discussion

The residential sector represents more than 30% of final energy consumption in France. Together with transport, it is the main energy-consumption sector. Consequently, investing in the energy-efficiency improvement of inefficient housing is considered to be a political and environmental priority. The law on energy transition and the Climate Plan provide for the renovation of 500,000 homes each year to eliminate 'thermal sieves' within 10 years.

Mainly from England and New Zealand, available international data suggests that the cost of investment in energy-efficiency improvement could be offset by health-expenditure savings. The results produced by our research confirm that, as in England, investment in a programme of energy-efficiency improvement would lead to savings for the French health system. These results are consistent with those of the 'Rénovons' initiative, where the estimated health system costs avoided (calculated using a different method) were 758 million euros a year. Also, our research showed that the benefits were greater for low-income households. The study shows the relevance and importance of monetising energy vulnerability.

In the UK, medical care from the National Health Service (NHS) is free of charge and specialists consider that the vast majority of persons living in England will use it, especially for cardiovascular and respiratory disorders. However, it is possible that a minority, especially those in insecure situations and/or those with mental-health problems, do not use this healthcare, even though it is free. In this case, it should be noted that this would lead to an underestimation of the likelihood of harmful health impacts and the related direct medical costs and so higher returns on thermal-renovation work. In this project, the health costs attributable to other factors of risks to health related to exposure to excessively low temperatures in the home, as well as dampness and mould growth and risks of domestic accidents, could not be included because Phébus did not assess those parameters. Costs related to poor mental health were not included, partly because when the HHSRS was devised, the related data were limited and remain scarce. Only direct medical costs were taken into account. Costs related to impacts on employment and education, where a causal link is difficult to determine and the available data still limited [10], were not taken into account. Despite this 'conservative' approach, the assessment of anticipated costs and benefits to health help to justify policies that aim to renovate inefficient housing, beyond the benefits in terms of reduced energy bills, energy consumption and GHG emission reductions, as well as the creation of jobs in the building sector.

In this type of approach over the medium term, the question of discounting is raised. The model uses a slightly theoretical pattern which will need to be completed by other, more realistic models taking into account different renovation and timeline scenarios. Sensitivity testing including a discounting rate for avoided medical costs of 3% over 22 years shows the same tendencies, with a benefit where thermally inefficient dwellings are occupied by households living below the poverty threshold.

For this research, we adapted the method based on the HHSRS developed in England, which enabled the correlation of housing and health data, giving a realistic picture of the connection between hazards and harm. The HHSRS identifies dwellings posing a potential risk to health – here, thermally inefficient housing – and enables action to be taken that will have a long-term benefit for the occupants, particularly the most vulnerable. That is the principle of the English approach focusing on the dwelling, very different from the approach taken in France. It is based on the fact that housing is the only factor that remains stable over time, unlike eminently variable human factors (occupancy rates, household makeup, activities of the occupants and possible moves to other dwellings). The methodology used is validated, simple, comprehensible and transferrable. It is widely accepted in England and Wales. However, the details and hypotheses used for this study have not been widely detailed before, and so all the stages of the project have been explained and all hypotheses justified. The British method was used in the absence of a similar French system. In France, national housing surveys conducted by the INSEE (French National Institute for Statistics and Economic Research) do not include questions on health, while health surveys – such as the EHIS-ESPS European survey on the health of the French – are self-reported and do not include data on housing conditions. So there are no national sources of correlated data on the health of occupants and their housing situation of the kind available in England.

For this research, we created the IPEL index based on the English approach, which better reflects the energy efficiency of housing, while the DPE currently used in France, expressed in primary energy, does not measure the intrinsic quality of buildings and does not enable the optimal detection of 'energy sieves'. In this study, we have refined the analysis with an additional stage enabling an estimation of what could be the impact on low-income households. The underlying hypothesis is that it will be those occupants least able to heat their home to a satisfactory temperature in cold periods who will be the most likely to suffer health problems related to that risk.

This research has certain limits. It is based on the hypothesis that, with the same level of thermal discomfort, a person in France will face the same risk to their health, especially of cardiovascular and respiratory disorders, as a person in England, which is likely but still to be demonstrated. The model used is not directly based on the measurement of temperatures in homes, but on the theoretical assessment of the energy performance of dwellings. The threshold of 38 for the IPEL was chosen arbitrarily, but sensitivity testing shows that thresholds ranging from 32 to 43 do not show greatly changed results.

Using a new index, the IPEL, based on the English approach, this research identified the 3.5 million inefficient homes in the stock of main residences in mainland France which should benefit from energy-efficiency improvement. It shows that investment in an appropriate, ambitious programme of energy-efficiency improvement is not only justified in terms of public health, but also cost-effective. The results of this research confirm that renovation should prioritise groups of inefficient homes occupied by low-income households and points to the necessity of facilitating the allocation of financial aid to the poorest households to enable them to renovate their homes.

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