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Energy poverty goes south? Understanding the costs of energy poverty with the Index of Vulnerable Homes in Spain

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Abstract

In southern European countries, despite having mild winters, many people live in cold and energy-inefficient properties and struggle to meet their energy needs for comfort and warmth, and therefore they run the risk of developing cold-related illnesses. Although the relationship between health, energy poverty, and cold/warm homes has been analysed by numerous studies, the identification of the direct impact of this relationship on society remains elusive in these countries. This paper shows a case study in a working-class district of Seville, Spain. Six multi-family residential buildings (providing social housing for a total of seventy-one households), built prior to energy-efficiency regulations being in place, are retrofitted by Seville City Council. The Index of Vulnerable Homes, defined by the authors, assesses the vulnerability to energy poverty (pre- and post-intervention) of those households. Furthermore, the costs to the National Health Service (NHS) are also estimated. The results show that savings for the NHS could be used in order to define the payback period of those retrofitting funds. In conclusion, this paper presents how the Index of Vulnerable Homes would be able to help in the development of a comprehensive and coordinated strategy in social housing to address energy poverty, and in the monitoring of the effectiveness of ongoing projects in the city of Seville.

Keywords

Energy poverty, Fuel poverty, Health, Vulnerable households, Energy efficiency, Health benefits

Highlights

- The costs associated to energy poverty vulnerability can be estimated
- Solving energy poverty is not only a matter of improving dwellings' energy efficiency
- The social benefit of retrofitting programmes can be addressed by the IVH

1. Introduction

Approximately 70% of the existing building stock in Mediterranean countries was built during 1960-1980, for instance in Portugal, Spain and Greece [1], whereby building renovations constitute a long-term solution to address the issue of energy poverty (EP), and provide affordable houses for most people vulnerable to EP. However, when discussing who are those most vulnerable households, it is important to bear in mind that they do not have the monetary capacity to carry out either any building improvement or equipment replacement [2], and it is therefore the responsibility of the government to develop effective measures to carry out these actions. In this respect, the Clean Energy for All Europeans package [3] states that Member States must acknowledge the prevalence of EP in their National Energy and Climate Plans and must propose a range of energy-efficiency measures to address this issue. The benefits of a building retrofit include not only the reduction of energy consumption, CO_2 emissions and resources, but also positively affect socio-economic aspects. One of the most important effects involves the savings for the National Health Service (NHS) related to EP [4–6]. In this context, it is known that many people living in cold and energy-inefficient properties struggle to meet their energy needs for comfort and warmth, and they therefore run the risk of developing cold-related health illnesses. Similarly, climate change is increasing the duration of hot weather, leading to a higher risk of EP, overheating, and health problems in most vulnerable households living in energy-inefficient houses [7,8]. Although the relationship between health, EP, and cold/warm homes has been analysed by a large quantity of studies [9], it remains difficult to identify the direct impact of this relationship.

Many worldwide studies (e.g., of Québec and Victoria in Canada [10], and of London in England [11]) have found higher rates of winter mortality in properties built before 1850 that have lower energy-efficiency ratings (28.2% winter mortality in contrast to 15% in properties built after 1980). Furthermore, the Warm Front scheme [12] reported that the mortality risk for colder outdoor temperatures was not suffered by the 64% of households that increased the indoor temperature in their houses to World Health Organization (WHO) levels (21°C in living rooms and 18°C in bedrooms for at least 9 hours a day) [13]. In addition to year of construction and energy-efficiency ratings, the maintenance level of indoor housing also constitutes a key factor in the health of a household. A poor level of maintenance of indoor housing is associated with damp homes with mould, which leads to a 45% increase in respiratory problems [14,15], as well as wheezing, colds, and viral diseases [16]. Socio-demographic factors such as ownership status, household size, type of building, educational level, household characteristics, also constitute key EP drivers which influence these figures [17–19].

Regarding social activities, a warm home is related to feeling comfortable at home, to not feeling ashamed to invite friends home, to an increase in day-to-day activities within those living spaces of the house that were previously impossible, and to a reduction in the worry regarding payment of energy consumption bills, thereby greatly reducing the impact on well-being [20,21]. Improvement in the energy efficiency of buildings has therefore been considered as one of the most important solutions to address EP. However, this paper highlights that this must be carefully considered, since: not all people living in energy-inefficient dwellings are in EP and vice versa [22]; special attention is needed when those households most vulnerable to EP are targeted, in order to prevent exclusion and inclusion inaccuracies in current EP policies [23]; and energy-efficiency measures should be a complement of social policies.

2. Background

The four primary indicators provided by the EU Energy Poverty Observatory [24] are used by Member States to assess EP: ‘Inability to keep home adequately warm’, ‘Arrears on utility bills’, ‘High share of energy expenditure in income (2M)’, and ‘Low absolute energy expenditure (M/2)’. However, the latest work carried out by Castaño-Rosa et al. [23] highlights the weaknesses of current EP indicators in providing a complete and feasible analysis, and the need to combine various indicators and to analyse their results together.

In recent years, a wide number of studies, which aim to evaluate the issue of EP by using various conventional and new variables, have been published: combining socio-economic indicators with the energy performance of buildings [25] or socio-demographic and geographical variables [19]; analysing the influence of climate [26]; the response of households to extreme heat and inadequate levels of indoor cooling [7,8], and the relationship with multi-dimensional measures of deprivation [27]; assessing the benefits of energy-efficiency measurements [28]; understanding householders’ behaviour as a driver of EP [29]; exploring the importance of emotions in energy vulnerability [30]; and the role of gender [31].

Regarding the case of Spain where the proposed work is carried out, the recently approved National Strategy against Energy Poverty [32] recognises that EP, defined as ‘the situation in which a household cannot meet its basic needs of energy supplies due to an insufficient level of income, which, in this case, may be aggravated by living in an energy-inefficient dwelling’, is a social issue which needs to be addressed. The four primary indicators available in the EU Energy Poverty Observatory [24] have been adopted for the assessment of EP and to carry out the nine lines of action defined to reduce EP: periodically calculate indicators and review reduction targets; increase the public housing stock and facilitate access to obtaining a dwelling; improve energy efficiency of buildings; incorporate renewable energies; promote education and awareness; and provide training. As a short-term palliative measure, social subsidies for electricity and the social heating subsidies have been redefined prioritizing three aspects: the universality of supply sources, automatization, and coordination with other public administrations. In the medium- and long-term, energy efficiency and building rehabilitation have been defined as measures. Spain has a noticeable climatic diversity due to its orography and geographical location, leading to different rates of EP in each Autonomous Community depending on the measure used [33]. For instance, based on the European Union Survey on Income and Living Conditions [34], EP represents low-income households living in autonomous regions with colder winters, which leads to excessive energy-consumption bills in relation to the income level. However, based on a survey on Living Conditions from the Spanish National Statistics Institute [35], EP includes households living in energy-inefficient dwellings with inappropriate heating systems (electric heaters). Warm and short winters in the southern part of Spain leads to disproportionate energy consumption during the coldest weeks [36]. These results make it difficult for policymakers to develop effective policies to address this issue and to target those households most vulnerable to EP. In this context, it is essential that each Autonomous Community, and local council, defines specific measures which reflect its singularities to effectively address EP. There are various studies carried out in Spain which underpin the need for specific actions: Mendoza Aguilar et al. [37] develop a specific indicator to measure EP in the Canary Islands; Sánchez-Guevara et al. [38] define a new methodology to evaluate EP based on the minimal thermal habitability conditions; Scarpellini et al. [39] assess the socio-economic impact of EP in the province of Teruel (Aragón); and Sanz-Hernández [40] analyses the impact of actors' engagement on the social perception of EP.

Regional regulation and specific measures have yet to be established in both the Autonomous Community of Andalusia and the city of Seville. However, the POWERTY project, "Renewable energy for vulnerable groups" [41], represents the first regional project which aims to enable vulnerable groups affected by EP to use renewable energy, in an effort to lead to the empowerment of vulnerable groups. In regard to this situation, the work presented herein aims to provide a feasible indicator that would help the development of a comprehensive and coordinated strategy to address EP in social housing in the city of Seville, which can be exported to the rest of Spain, in addition to monitoring the effectiveness of ongoing projects. To this end, the Index of Vulnerable Homes (IVH) [42], is applied to a real case study in a working-class area of the city of Seville composed of six multi-family residential buildings, which constitute a total of seventy-one households living in social housing, in order to assess the initial situation of EP vulnerability. An energy-efficiency intervention is then carried out, which reduces the initial energy demand and the EP vulnerability, improves the quality of life of each household, and cuts down the costs to the NHS in terms of costs per life year saved. Furthermore, the payback period of the retrofitting projects is estimated in terms of savings to the NHS in each project, thereby making it possible to assess its potential social benefit. The result is the first local case study in a Mediterranean climatology (city of Seville) that shows the high prevalence to EP vulnerability in warmer countries and describes how the IVH would be able to help in the development of a comprehensive and coordinated strategy in the city of Seville in response to the National Strategy against Energy Poverty. This strategy could also be applied across Spain, could lead to the effective deployment of public funding, by targeting those groups that are most vulnerable to EP, improving the quality of household life, and consequently reducing the NHS costs related to EP.

3. Methodology

This work uses qualitative data to examine the current level of EP vulnerability in six multi-family residential buildings, a total of seventy-one households with low income, within a working-class area located in the North of the city of Seville, by applying the IVH. The archetypical building type in Seville is analysed [43]. The IVH is composed of four main components: Monetary Poverty Indicator (MPI), Energy Indicator (EnI), Comfort Indicator (CI), and Health-Related Quality-Life Cost (HRQLC) [42].

Monetary Poverty Indicator (MPI): The economic vulnerability of the dwelling on the basis of household net income is analysed by using the Monetary Poverty Threshold (MPT) and the Severe Monetary Poverty Threshold (SMPT), both of which depend on the local area. The MPT is defined as 60% of median equivalised disposable income in the area studied (Seville, Spain) with Eurostat [44] statistics. The SMPT, the most precarious level of poverty, is set at the amount of social benefit granted by the government to families in social exclusion in Spain [45]. Table 1 below shows the various annual thresholds set for the city of Seville.

Table 1. Poverty thresholds in Seville (Spain) (Source: Authors' own).

Nº people	*Monetary poverty (€)*	*Severe monetary poverty (€)*
One person	8,114	4,800
Two people	12,171	7,200
Two adults and one child	14,605	8,640
Two adults and two children	17,040	10,080
Two adults and three children	19,474	11,520

The MPI is defined using equation (1):

$$MPI = \frac{NI}{T} \quad (1)$$

where *NI* is net income and *T* is the poverty threshold, which depends on the country or region. A household is therefore said to be in monetary poverty or severe monetary poverty if its net income falls below the set threshold (MPI < 1.00).

Energy Indicator (EnI): This denotes the energy vulnerability of a house on the basis of its required energy consumption (modelled demand). This is compared with the energy threshold set according to the median energy consumption required (energy demand) for the type of building in the case study. Using modelled demand avoids the influence of households' behaviour (due to the priorities, characteristics, and customs of households) on the evaluation.

The EnI is defined using equation (2):

$$\text{EnI} = \frac{\text{EC}}{\text{MEC}} \quad (2)$$

where *EC* is energy consumption required (modelled demand obtained from the software simulation); *MEC* is the median energy consumption required (energy demand) for the type of building in the area of study obtained from official statistics (the latest data published by the Institute for the Diversification and Savings of Energy [46] is used for the case study in Seville, Spain). Therefore, the housing energy consumption is considered "admissible" if it is below the energy threshold (EnI < 1.00), otherwise it is considered "inadmissible" (EnI > 1.00).

Comfort Indicator (CI): This analyses the environmental dwelling vulnerability by using the percentage of hours that living spaces fall outside the set range of comfort. Eighty percent of hours in thermal-comfort situation is used as the comfort threshold, meaning that occupants may be thermally uncomfortable for nearly 5 hours per day; these are considered to be sleeping hours [47]. Category I, the most stringent criteria, for the living room, and Category III, a wide comfortable-temperature range, for bedrooms, are employed to define the different thermal-comfort ranges according to the normative EN 15251:2007 [48]. The CI result is therefore "admissible" if the percentage of hours in thermal comfort is equal to or greater than 80% (CI ≥ 80%).

Health-Related Quality-Life Cost (HRQLC): As an innovative aspect in the assessment of EP vulnerability, the HRQLC provides an economic analysis of a vulnerable situation and is defined by ascribing a range of monetary values to the Quality-Adjusted Life Year (QALY) defined in each level of vulnerability. The QALY, a traditional measure to evaluate the state of health of people, is calculated by using the EQ-5D-5L Index Value Calculator [49] on the basis of five different levels of health (from level 1, the best, no health problems, to level 5, the worst, extreme problems) according to five dimensions (Mobility, Self-care, Usual activities, Pain/Discomfort, and Anxiety/Depression). The cost-effectiveness value of human life, which represents the costs to the NHS associated to maintaining a person in a state of perfect health for one year, set between €28,000-35,000 by the Spanish National Health Service [50,51], was used in this case study in Seville in order to ascribe the monetary value to the different QALYs defined in each level of vulnerability. The process behind these figures is explained further in Castaño et al. [42].

Table 2 shows the many levels of vulnerability defined in the IVH after combining various indicator results (thirteen vulnerable levels that define different situations of vulnerability depending on householders' state of health and the consequences of being in said situation). Furthermore, the QALY defined in each level of vulnerability and the HRQLC ascribed are both given (see Castaño et al. [42] for further details).

Table 2. Levels of vulnerability [42].

Level	Variables			QALY	HRQLC (£)
1	MPI: NMP	EnI: Admissible	CI: Inadmissible	0.910	2700
2	MPI: NMP	EnI: Inadmissible	CI: Admissible	0.857	4290
3	MPI: NMP	EnI: Inadmissible	CI: Inadmissible	0.825	5250
4	MPI: MP	EnI: Admissible	CI: Admissible	0.786	6420
5	MPI: MP	EnI: Admissible	CI: Inadmissible	0.754	7380
6	MPI: SMP	EnI: Admissible	CI: Admissible	0.642	10,740
7	MPI: MP	EnI: Inadmissible	CI: Admissible	0.620	11,440
8	MPI: MP	EnI: Inadmissible	CI: Inadmissible	0.484	15,480
9	MPI: SMP	EnI: Admissible	CI: Inadmissible	0.358	19,260
10	MPI: SMP	EnI: Inadmissible	CI: Admissible	0.309	20,730
11	MPI: SMP	EnI: Inadmissible	CI: Inadmissible	-0.008	30,240
12	MPI: MP	EnI: Inadmissible*	CI: Inadmissible	-0.096	32,880
13	MPI: SMP	EnI: Inadmissible*	CI: Inadmissible	-0.311	39,330

* The household cannot afford minimum energy consumption due to lack of monetary resources. NMP: No monetary poverty; MP: Monetary poverty; SMP: Severe monetary poverty.

Figure 1 shows the assessment process of the IVH for the analysis of EP vulnerability. The IVH identifies the initial situation of vulnerability in each project and, in accordance with the results, an energy-efficiency intervention is defined. Subsequently, with a reduction in EP vulnerability and, consequently, in NHS costs, EP is eliminated in certain cases. However, this situation can persist in low-income households. The remaining EP vulnerability is assessed again by the IVH, whereby the most effective actions from a financial point of view are identified in each case study (fuel payment, social tariffs, connection guarantee, etc.) so that EP vulnerability can be alleviated during severe weather periods.

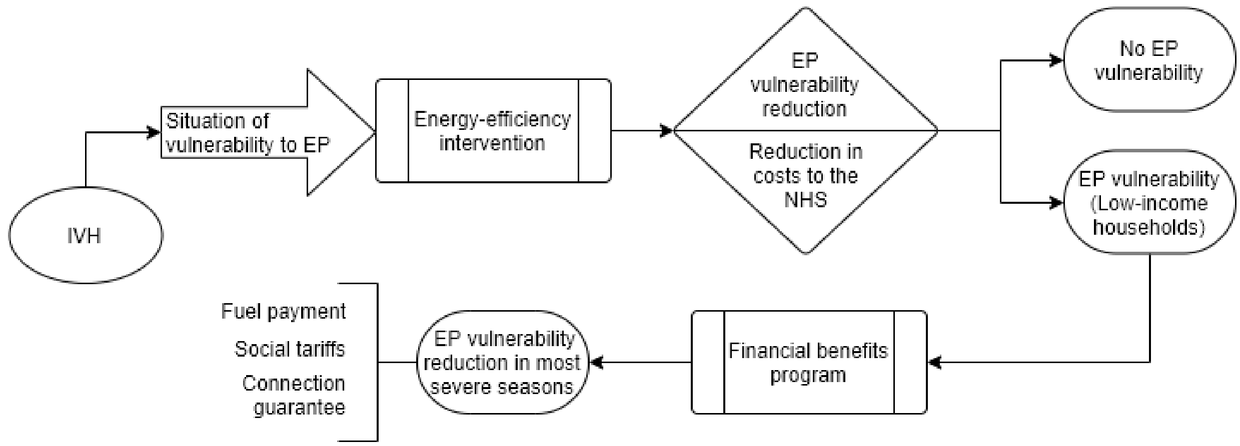


Figure 1. Theoretical process for the assessment of EP vulnerability by applying the IVH (Source: Authors' own).

4. Case study: Area of Concerted Rehabilitation

Although the Index of Multiple Deprivation (IMD) [52] in the UK was not originally developed to assess EP, it is one of the most commonly used indices in the UK for the provision of a relative measure of deprivation for small areas. The Area of Concerted Rehabilitation is a similar instrument employed to identify the residential historical heritage in the cities of Andalusia with low-income households, a lack of minimum urban services, poor quality buildings, and/or social exclusion [53]. Amongst other areas, this paper analyses the second largest district of the historical centre of Seville, which represents 60% of its population and has, on average, 104 dwellings per square mile [35]. The area is also the poorest and in bad condition. In this context, in 2007, this district was declared an Area of Concerted Renovation by the Regional Government of Andalusia, and Seville's City Council put in place a retrofitting plan and special funding for its development. The main goals of this ambitious plan included improving the energy efficiency of buildings and life quality, and providing better urban services. However, by 2011, only 10% of the total buildings had been completed, and the initiative came to a halt due to the financial crisis, with over 60% of the households still living in a vulnerable situation with respect to EP (see Table A1 for further sociodemographic information). Low-income households tend to live in energy-inefficient buildings and these vulnerable households are not targeted by current initiatives; public money is therefore not effectively reducing EP. This work uses qualitative data (six multi-family residential buildings with a total of seventy-one households with low income) to assess the current level of EP vulnerability within a working-class area classified as a vulnerable neighbourhood according to the Spanish Vulnerable Neighbourhood Catalogue [54]. This vicinity is located in the northern part of the historical centre of the city of Seville. The six selected multi-family residential buildings were chosen from one of the retrofitting projects carried out by Seville City Council. Figure 2 shows the location of the six multi-family residential buildings (red spots) within the case study area (delimited by yellow lines).

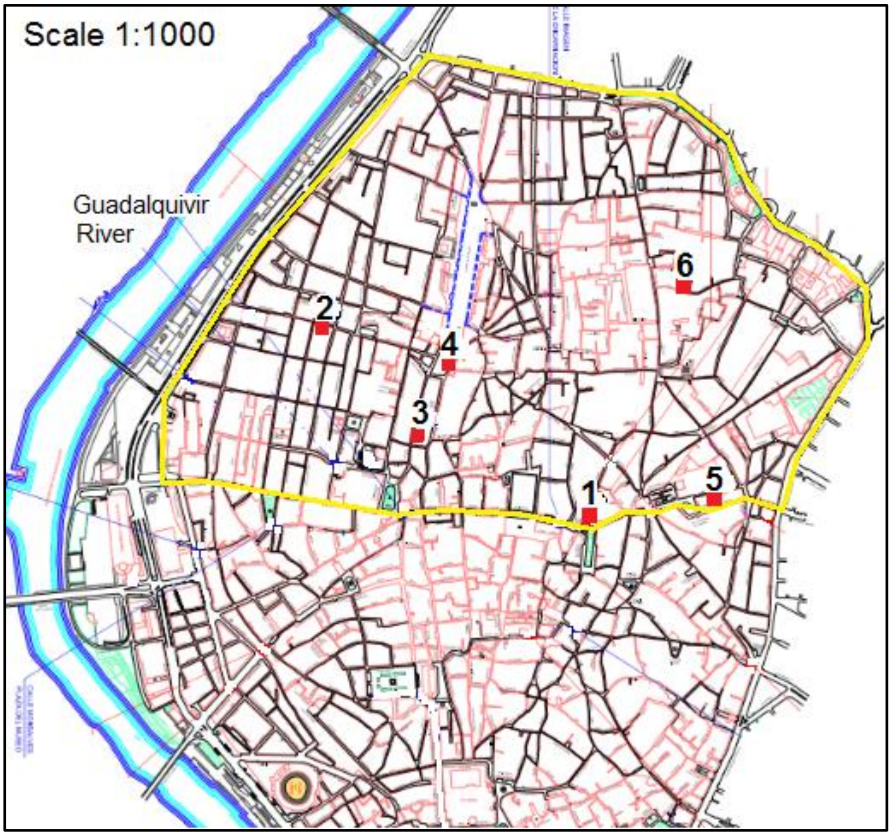


Figure 2. Location of the multi-family residential buildings analysed within the case study area (Source: Authors' own).

Social workers have played a key role in the detection and monitoring of EP in Spain [55], as well as in other European countries; they are the mediators who detect a situation of EP by interacting with households on a daily basis. In this work, the Department of Social Services of Seville City Council, which is composed of certified agents with specific training and tools to properly assess the causes of EP, played a key role in the data collection; the monetary and social situation, outstanding bills, and typology of the households were assessed, thereby defining the type of aid needed for each family. Note that due to concerns about breaching data protection regulations, only information regarding the monetary situation and state of health of households was available, together with photos of the main pathologies (see Figure 3). Various interviews for the data collection were conducted during winter (this represents the most severe season in terms of EP in Andalusia [56]), and information about the composition of the survey used during the interviews is provided in the Annexe (Table A2). Urgent monetary aid to help households pay their outstanding bills was proposed by the Department of Social Services. However, as a result of the beginning of the financial crisis in Spain, only one package of energy-efficiency measures to improve building characteristics was approved, which left many ongoing plans paralysed. The six selected multi-family residential buildings represent those most vulnerable households who live in a situation of monetary poverty within energy-efficient buildings (after an energy-efficiency intervention) and, as a result, are excluded from the analysis by current measures used for the analysis of EP.

The eligible buildings represent the typical types of buildings in this area and were included in one of the retrofitting projects carried out by Seville City Council, funded by the Ministry of Andalusia, in 2012, in accordance with the Area of Concerted Rehabilitation instruments. The six residential buildings analysed were built before the introduction of the first energy-efficiency regulations in Spain (CT-79) [57] and consequently suffer from poor energy conditions. Multi-family residential buildings built before 1980 constitute the most representative archetype in the city of Seville, 33.1% out of the 60% of the total population that live in the area [58]. Furthermore, these buildings have hitherto failed to follow even a minimum level of maintenance [43] (residents cannot afford to pay for both minimum maintenance tasks and energy-efficiency improvements, mainly due to their low income), resulting in low health standards, inadequate thermal-comfort temperatures in the dwellings, and an increased risk of well-being issues [59,60]. Although the six residential buildings analysed vary in terms of the number of storeys, the year of construction and the structure of the dwellings remain similar. The standard dwelling comprises a bathroom, a kitchen, a living room, and three bedrooms. Table 3 shows the description of the construction of the buildings and the characteristics of the dwelling systems. Note that Table 3 is applied to the six residential buildings analysed due to their similar characteristics. It should be borne in mind that these buildings, like the majority of the buildings within this area, have a single electricity meter. This means that the cost of the total energy consumption of the building is divided between all householders, all of whom pay the same amount of money independent of their actual energy consumption.

Table 3. Description of building construction and characteristics of dwelling systems [61].

Element	*Description*	*U-values (W/m^{2}K)*
Walls	Solid brick, as built, no insulation	1.35
Roof	Pitched without insulation	2.30
Floor	Reinforced concrete raft with no insulation added	1.81
Ground floor	Reinforced concrete ground floor with no insulation	1.50

Windows	Double-glazed windows in wooden frames	3.88
Doors	Wooden door with frames of similar material	3.00
Party wall	Same as external walls	2.35
System	*Description*	
Heating	Electric room heaters, 100% climatized area	
Air-conditioning	Electric multi-split device, 100% climatized area	
Domestic hot water	Butane gas boiler, nominal power of 9.55 kW, efficiency of 85% and 53.56 m^3/day	
Others	Electricity	

The operational parameters for each room type were established under the consideration that householders could spend most of their time at home (Table 4) in order to include vulnerable householders, such as the unemployed, students, and/or severely disabled.

Table 4. Occupancy profile used in the simulation (Source: Authors' own).

Room occupied	*Monday to Friday*	*Saturday and Sunday*
Living Room	9am – 12pm; 1pm – 6pm; 7pm – 11pm	10am – 12pm; 1pm – 6pm; 7pm – 11pm
Kitchen and Dining area	8am – 9am; 12pm – 1pm; 6pm – 7pm	9am – 10am; 12pm – 1pm; 6pm – 7pm
Bedroom 1	11pm – 8am	11pm – 9am

The energy consumption required for each residential building was obtained from the dynamic simulation in the modelling software Energy Plus 7.0 [62] and the official Spanish software CE3_Viviendas [63], the tool currently employed to predict energy consumption for existing residential buildings in Spain and to determine the energy-efficiency rating. Table 5 below shows the energy data of the analysed buildings depending on the floor area and the energy-efficiency rating. This kind of retrofitting project focuses on the energy-efficiency characteristics of the whole building instead of each individual dwelling. A global vision of the building, instead of single-family dwelling, helps to better evaluate the retrofitting. Therefore, the required energy consumption obtained represents the total energy consumption required by the whole building instead of that by each individual dwelling (household). In this way, an energy-efficiency intervention in a multi-family residential building with low-income households can be evaluated. It is important to highlight that this consideration can be applied on the condition that all households are of low income, by focusing on those areas most vulnerable to EP. Otherwise, it would be impossible to analyse the level of EP vulnerability of a multi-family residential building if each household had a different level of income, since not all would be in a situation of monetary poverty.

Table 5. Energy data of the buildings analysed (Source: Authors' own).

Project	*Total energy consumption (kWh/m²year)*	*Total energy consumption (kWh/year)*	*Energy-Efficiency Rating*
01	49.05	91,233	G
02	63.14	34,348	G
03	53.80	51,271	F
04	34.28	63,760	G
05	45.79	49,041	F
06	38.19	48,768	F

Additionally, Figure 3 shows an overview of the main defects found in the six multi-family residential buildings (projects) during the technical inspection carried out by the Department of Social Service of Seville City Council. Note that the householders' main health problems associated with the different pathologies found during the technical inspection are analysed and listed in the Annexe (Table A3).

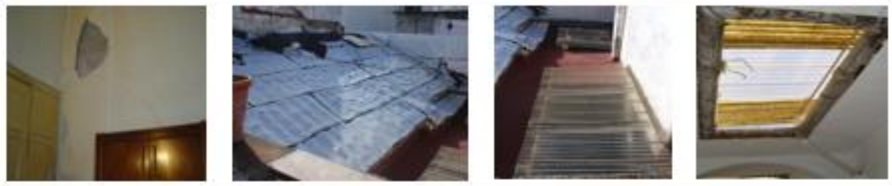
Project	Main pathologies
P_01 Year of construction: 1932 Floors: 4	
P_02 Year of construction: 1940 Floors: 2	
P_03 Year of construction: 1942 Floors: 4	
P_04 Year of construction: 1959 Floors: 5	
P_05 Year of construction: 1959 Floors: 5	
P_06 Year of construction: 1970 Floors: 4	

Figure 3. Overview of main pathologies found in the six buildings analysed (Source: Author's own based on [43,61].

5. Results

After defining the proposed case study, this section presents results from the application of the IVH according to each indicator.

Monetary Poverty Indicator (MPI): As explained above, after analysing the information provided by the Department of Social Services (from the interviews), the result is that all of households who live in any of the six multi-family residential buildings analysed are living in a situation of monetary poverty. The result of the MPI for the six projects is therefore "Monetary poverty". Note that size and typology have been assumed as being the same for all households, since all households within the case study are living in a situation of monetary poverty independently of the number of family members.

Energy Indicator (EnI): The energy analysis was carried out by setting the energy threshold to the median energy consumption required by the type of dwelling within the case study according to the data of energy consumption in Spain as published by the Institute for the Diversification and Saving of Energy [64]. Table 6 below shows the results of the EnI depending on the characteristics of the dwellings (Table 3).

Table 6. Results of the Energy Indicator depending on the characteristics of dwellings (Source: Authors' own).

Project	*Total energy consumption (kWh/year)*	*Energy consumption threshold (kWh/year)*	*EnI*
01	91,233	77,784	Inadmissible
02	34,348	23,441	Inadmissible
03	51,271	41,085	Inadmissible
04	63,760	52,703	Inadmissible
05	49,041	40,162	Inadmissible
06	48,768	37,622	Inadmissible

Note that, according to the Buildings Performance Institute Europe (BPIE), those residential buildings whose energy demand can exceed 200 kWh/m^2 are considered old and inefficient buildings [19], and this underpins the "inadmissible" results for the dwellings analysed.

Comfort Indicator (CI): The percentage of hours that each dwelling lies within and outside the comfort range was analysed for the six projects. Note that each dwelling was analysed independently and, due to the characteristics of the dwellings (none of the dwellings had been retrofitted, and hence the same technical characteristics remained for all 6 projects) and to the climatology characteristics of the area (Mediterranean climate, Seville), the results were very similar for the dwellings of each project. Table 7 summarizes the comfort analysis for each project. It should be borne in mind that it might not be possible to carry out this thermal-comfort analysis in other building typologies or other countries, since the thermal-comfort situation could vary between dwellings depending on floors, level of retrofit, etc. On analysing the results detailed in Table 7, it can be observed that either "Autumn" or "Spring" could have been excluded from the analysis since their thermal-comfort values are highly similar.

Table 7. Analysis of hours of comfort depending on each project analysed (Source: Authors' own)

Project		*Summer*	*Winter*	*Spring*	*Autumn*
01	Hours in discomfort	0.96%	95.21%	4.68%	4.02%
	Hours in comfort	**99.04%**	4.79%	**95.32%**	**95.98%**
02	Hours in discomfort	10.55%	98.26%	15.69%	15.08%
	Hours in comfort	**89.45%**	1.74%	**84.31%**	**84.92%**
03	Hours in discomfort	1.92%	95.98%	6.67%	6.11%
	Hours in comfort	**98.08%**	4.02%	**93.33%**	**93.89%**
04	Hours in discomfort	8.44%	97.44%	13.61%	13.01%
	Hours in comfort	**91.56%**	2.56%	**86.39%**	**96.99%**
05	Hours in discomfort	3.98%	96.11%	9.79%	9.13%
	Hours in comfort	**96.02%**	3.89%	**90.21%**	**90.87%**
06	Hours in discomfort	9.14%	97.96%	14.88%	14.06%
	Hours in comfort	**90.86%**	2.04%	**85.12%**	**85.94%**

Table 7 below shows the situation of vulnerability to EP of those households living in the six multi-family residential buildings within the analysed area of the city of Seville (classified as an area of concerted rehabilitation). Note that the vulnerable situation is the same for all households due to the assumption of the situation of monetary poverty in the MPI for all these households and to the poor quality of the buildings. The HRQLC provided in Table 8 represents costs per life year to the NHS of those households living in the multi-family residential building analysed depending on the number of households in each project (building), leading to higher HRQLC in those buildings with a greater number of households.

Table 8. Results of the IVH application per project (Source: Authors' own).

Project	*Season*	*IVH*	*HRQLC (€)*
01	Summer, Spring, Autumn	7	325,080
(N:21)	Winter	8	
02	Summer, Spring, Autumn	7	123,840
(N:8)	Winter	8	
03	Summer, Spring, Autumn	7	92,880
(N:6)	Winter	8	
04	Summer, Spring, Autumn	7	232,200
(N:15)	Winter	8	
05	Summer, Spring, Autumn	7	185,760

(N:12)	Winter	8	
06	Summer, Spring, Autumn	7	139,320
(N:9)	Winter	8	

N: number of households living within the multi-family residential building.

On analysing the results from Table 8, it can be stated that the costs to the NHS related to EP can be estimated by applying the IVH (e.g., project 01, which is comprised of 21 households, incurs an estimated cost of 325,080€ to the NHS). Furthermore, it is shown that, while always assuming the same monetary situation for all households living within the multi-family residential building, those buildings with a larger number of households would imply a greater level of vulnerability, and consequently a higher cost to the NHS (HRQLC).

5.1. Energy-efficiency intervention: savings for the NHS

This section shows, by defining an energy-efficiency intervention in the six analysed buildings, how the IVH would allow Seville City Council to assess the reduction in EP vulnerability and improvement of the quality of life of households. The energy-efficiency measures carried out in the retrofitting programme (defined in the Typology Approach for Building Stock Energy Assessment (TABULA) project [65]) consisted of: improving building construction in the form of cavity wall insulation, loft insulation, and UPVC (unplasticized polyvinyl chloride) double-glazed windows; and installing a new solar-thermal system. Table 9 describes the combination of energy-efficiency measures in order to improve the building and its running costs.

Table 9. Energy-efficiency measures installed in the building construction [66].

Measures	*Baseline U-values (W/m^2K)*	*Improved U-values (W/m^2K)*	*Cost per floor area*
Cavity wall insulation	1.35	0.83	25.61 €/m^2
Loft insulation	2.30	0.21	37.75 €/m^2
UPVC double-glazed windows	3.88	1.98	512.84 €/m^2

Regarding the system improvement, the existing butane gas boiler (typical water-heating system installed in these building typologies) was removed, and a new solar-thermal system (100% renewable energy) was installed, leading to a reduction in the energy consumption related to the hot-water system. The cost of the solar-thermal system is 314.47 €/m^2 [66] which includes the labour cost of uninstalling the old equipment.

The energy consumption required by the buildings after having applied the energy-efficiency measures was obtained from dynamic simulation by defining the new building configuration in the modelling software Energy Plus 7.0 [62] and in the official Spanish software CE3_Viviendas [63]. The operational parameters for each room type remained the same as those detailed in Table 4.

Figure 4 provides a graphically comparative analysis between the energy consumption in buildings before and after the energy-efficiency intervention. Orange and pink colours represent the initial and final energy consumption, respectively. The red line indicates the energy consumption threshold. The final energy consumption is lower than the threshold in all projects, and the EnI becomes "Admissible".

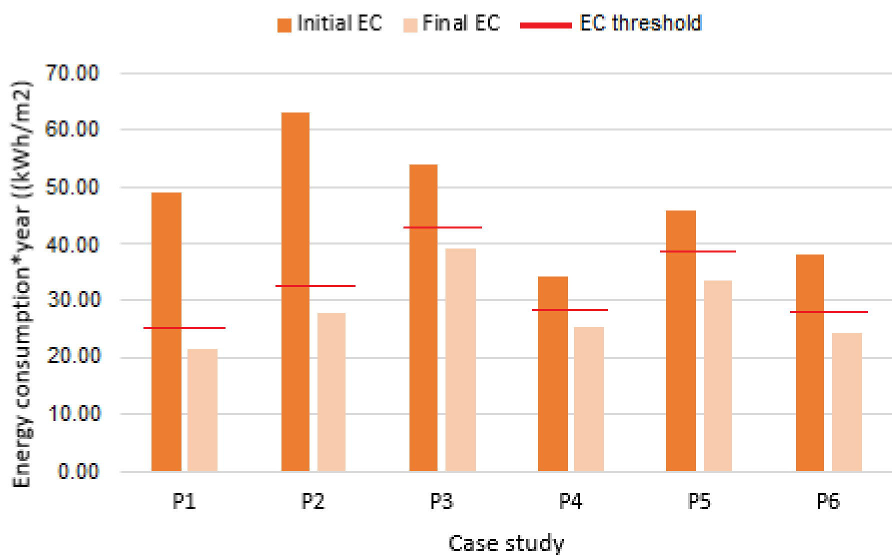


Figure 4. Comparative analysis between the energy consumption before and after the intervention (Source: Authors' own).

Regarding thermal comfort, Table 10 summarizes the comfort analysis for each project after the energy-efficiency intervention. Note that the thermal-comfort situation was considerably improved in winter due to the insulation measures installed. However, the CI result was still "Inadmissible" in winter, due to the configuration and year of construction of the buildings, while the summer, spring and autumn periods became "Admissible". These CI results (poor thermal comfort during winter in Spain) in terms of obtaining an "Admissible" percentage of hours in thermal-comfort situations all year round are very common when either old single-family or multi-family residential buildings are analysed. It is impossible to reach an improvement of 100% effectivity when only an austere public budget is available to address this issue.

Table 10. Analysis of hours of comfort depending on the project analysed (Source: Authors' own).

Project		*Summer*	*Winter*	*Spring*	*Autumn*
01	Hours in discomfort	0.96%	47.09%	4.68%	4.02%
	Hours in comfort	**99.04%**	52.91%	**95.32%**	**95.98%**
02	Hours in discomfort	10.55%	53.52%	15.69%	15.08%
	Hours in comfort	**89.45%**	46.48%	**84.31%**	**84.92%**
03	Hours in discomfort	1.92%	48.92%	6.67%	6.11%
	Hours in comfort	**98.08%**	51.08%	**93.33%**	**93.89%**
04	Hours in discomfort	8.44%	51.33%	13.61%	13.01%
	Hours in comfort	**91.56%**	48.67%	**86.39%**	**96.99%**
05	Hours in discomfort	3.98%	49.09%	9.79%	9.13%
	Hours in comfort	**96.02%**	50.91%	**90.21%**	**90.87%**
06	Hours in discomfort	9.14%	52.55%	14.88%	14.06%
	Hours in comfort	**90.86%**	47.45%	**85.12%**	**85.94%**

Table 11 shows the IVH results before and after the energy-efficiency intervention and provides details of the reduction in EP vulnerability and improvement of the quality of life of households. Furthermore, savings, in terms of life years saved, are estimated for the NHS. The savings for the NHS have been calculated by subtracting the costs to the NHS after the energy-efficiency intervention (146,790€ for project 01) from the initial costs to the NHS (325,080€ for project 01). The costs to the NHS (HRQLC) are associated with each level of vulnerability (see Table 2 for details) and this is further explained by Castaño-Rosa et al. [42], therefore a reduction in the level of vulnerability after an energy-efficiency intervention also leads to a reduction in the costs to the NHS. It should be highlighted that these values must be carefully considered due to the subjective aspect of EP vulnerability and the difficulties of assessing the cost associated to a human life, leading therefore these results to be cautiously interpreted. Note that the situation of monetary poverty of a household remained the same from the initial case study, which leads to no change in the MPI: no financial benefit was provided to households, and only dwelling characteristics were improved.

Table 11. Results of the IVH application per project before and after the intervention (Source: Authors' own).

Project	*Season*	*IVH (Before)*	*IVH (After)*	*HRQLC (€) (Before)*	*HRQLC (€) (After)*	*Savings for the NHS (€)*
01	Summer, Spring, Autumn	8	4	325,080	146,790	178,290

(N:21)	Winter	7	5			
02 (N:8)	Summer, Spring, Autumn	8	4	123,840	55,200	68,640
	Winter	7	5			
03 (N:6)	Summer, Spring, Autumn	8	4	92,880	41,400	51,480
	Winter	7	5			
04 (N:15)	Summer, Spring, Autumn	8	4	232,200	103,500	128,700
	Winter	7	5			
05 (N:12)	Summer, Spring, Autumn	8	4	185,760	82,800	102,960
	Winter	7	5			
06 (N:9)	Summer, Spring, Autumn	8	4	139,320	62,100	77,220
	Winter	7	5			

N: number of households within the multi-family residential building.

Figure 5 provides a graphically comparative analysis between the savings in terms of cost per life year for the NHS of those households living in the multi-family residential building analysed. It should be taken into account that the HRQLC was reduced by over 50% in all projects. These results are backed by the latest NHS report [44]. In 2012, when the retrofitting took place, the cost per household to the NHS was estimated at €3,546.36. In terms of primary care, this amount is reasonably similar to the savings for the NHS which are estimated by the IVH to be €3,945.21 (this is the difference between the cost to the NHS estimated by the IVH before and after the retrofitting divided by the number of households within the multi-family residential building (Figure 5)). The values in Figure 5 represent the total costs of six different multi-family residential buildings, each of which has a different number of households (seventy-one in total). Due to this difference, these numbers are taken into consideration in order to estimate the cost per project (Table 11). Additionally, it should be highlighted that after the different energy-efficiency interventions came to an end, according to the process defined by the Department of Social Service of Seville City Council for this intervention, social workers visited and collected evidence from households, thereby enabling the effectiveness of each intervention to be assessed. Households reported ‘better thermal comfort’; ‘increased day-to-day activities in spaces that were previously non-habitable’; ‘decreased concern regarding energy bills, leading to household empowerment’; ‘increased motivation and invitation of friends to the home’.

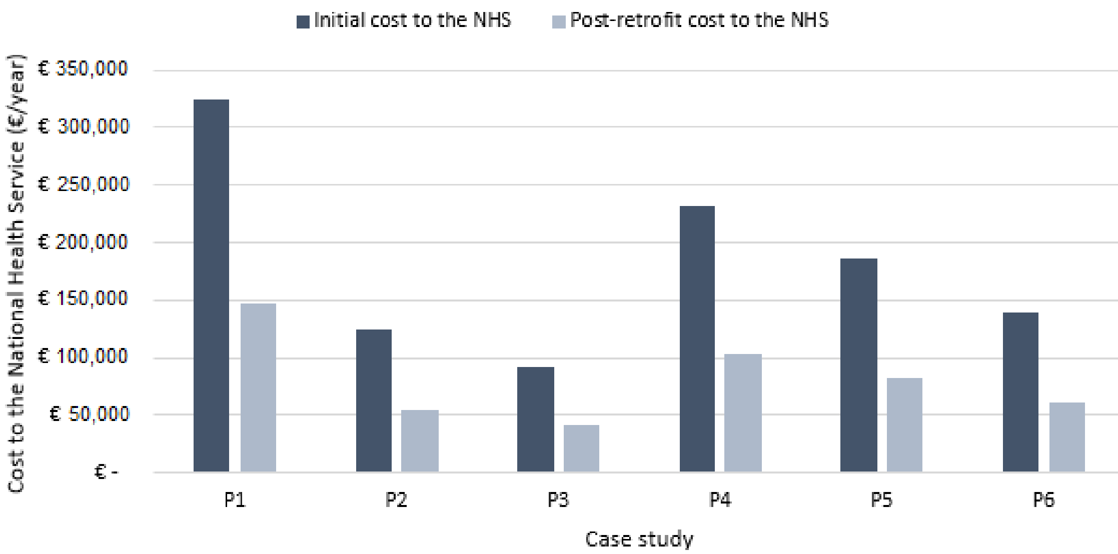


Figure 5. Cost to the NHS per life year before and after the intervention (Source: Authors' own).

6. Discussion

In the analysis of the results of the IVH, EP vulnerability is presented in the six multi-family residential buildings studied (a total of seventy-one households). The reduction in EP vulnerability after the retrofitting is also assessed, and savings for the NHS per household and year in terms of life years saved are estimated. However, it is important to note that these households are still living in monetary poverty, and as a result, a slight EP vulnerability persists. Current EP indicators applied to Spain fail when considering type and size of household, tenure status, characteristics of the dwelling (age of construction, heating system, typology, etc.), area of residence, or employment status, and therefore create 'false positive' (households that are not energy poor but meet the criteria defined) and 'false negatives' (households that are energy poor but are not recognised in EP) [67]. This work shows that the IVH solves these inaccuracies and, as an innovative aspect, allows the vulnerability to EP of a household after an energy-efficiency intervention to be assessed.

In regards to the link between energy retrofitting and improving the health of occupants in the context of Spain, J. Ortiz et al. [59], who analyse the effects of energy-efficiency intervention on occupants' health (caused by low indoor temperatures) and estimate the potential savings for the Spanish NHS, and A. Peralta et al. [68], who evaluate the impact of energy-efficiency façade interventions on occupants' health, constitute the most representative studies in this respect. However, the benefit of energy-efficiency retrofitting in improving the health of households and, consequently, yielding savings for the NHS has still to be comprehensively documented in Spain. By applying the IVH to a vulnerable neighbourhood within the city of Seville, this work shows that for the cost of energy-efficiency retrofitting and the savings for the NHS (estimated from the application of the IVH), the Spanish government payback period could be estimated (of the funds to promote energy-efficiency) and therefore illustrates how public money can be effectively employed for those households in greatest need. Figure 6, using project 3 as an example, shows the payback period graphically. The amount invested in project 3 is €110,967. The EP vulnerability had been reduced one year later and, consequently, the reductions in NHS costs saved €51,480. Similarly, two years later, the annual savings remain the same (they are now living in energy-efficient buildings with improved characteristics) and the initial investment has almost completely been recovered. Finally, after three years, monetary resources of the Spanish government are available, which stand at €43,473. This financial benefit can be used to help those households who remain in EP, by paying their energy bills, providing social tariffs, guaranteeing grid connection, etc.

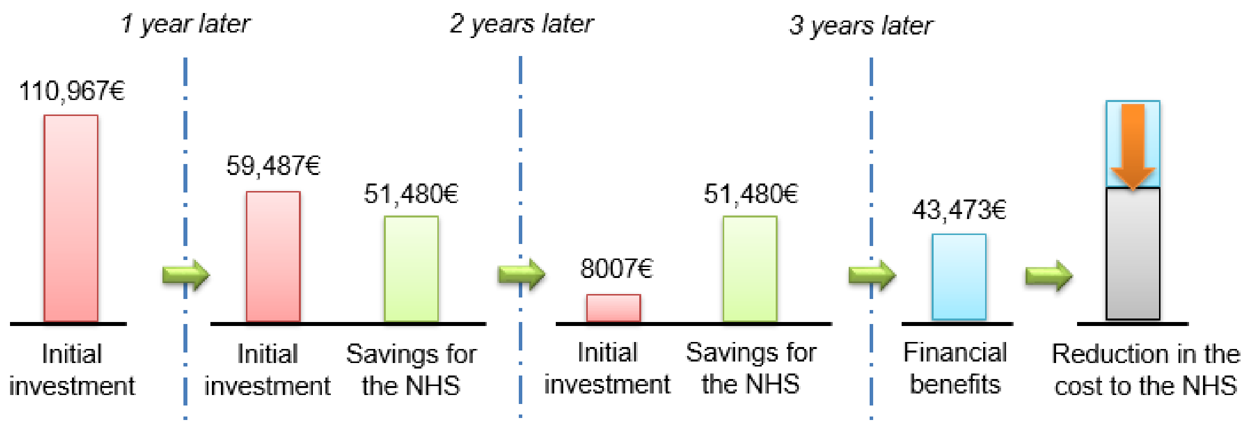


Figure 6. Graphical analysis of the amortization schedule in terms of savings for the NHS (project 03) (Source: Authors' own).

Furthermore, Figure 7 shows the payback period of each project according to the retrofitting costs and savings for the NHS. The costs in Table 8 are employed to calculate the total project costs. It can be observed that none of the projects recover their investment during the first year (red bars): one year and five months is the minimum payback period. However, projects 1, 4, 5, and 6 pay back within the second year (brown bars), and the remaining projects in the third year (yellow bars).

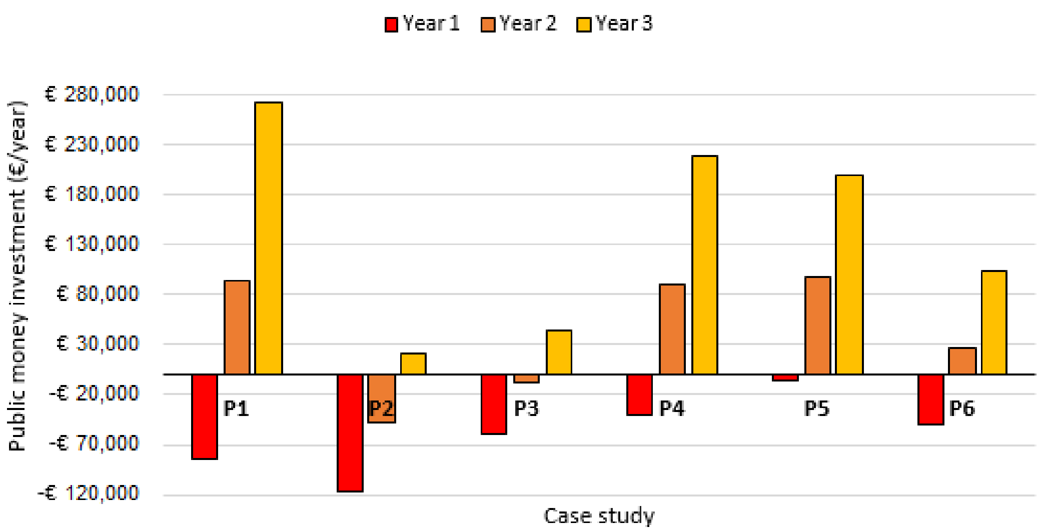


Figure 7. Graphical analysis of the proposed amortization schedule for each project (Source: Authors' own).

It should be highlighted that these results must be cautiously interpreted since: the data to calculate the costs associated to various health issues is limited; the perception of energy-efficiency intervention differs according to each occupant [69]; the economic assessment is estimated for a one-year period, but the effect of the intervention can last longer; this work estimates the savings for the NHS caused by a reduction in the level of vulnerability. However, the lack of research in Spain, as well as the associated complexity, is taken into consideration in this work, which enables estimations to be made of the reduction in the level of vulnerability after an energy-efficiency intervention and of the related savings for the NHS. In this context, further research is therefore needed in order to provide a theoretical framework of the cost associated to EP.

7. Conclusions

In Spain, the National Strategy against Energy Poverty recognises EP as a social issue which urgently needs to be addressed. However, current indicators adopted for the assessment of EP only provide gross figures which obstruct the identification of households vulnerable to EP, thereby making it difficult for policymakers to effectively address this issue. Furthermore, Spain presents a marked climatic diversity due to its orography and geographical location, which leads each Autonomous Community, and local council, to define specific measures that reflect its singularities. This work, by using qualitative data, presents a real-life local case study in a vulnerable neighbourhood within the city of Seville that shows, by applying the IVH, how those households living in social housing that are most vulnerable to EP (low-income householders living in poor-quality buildings within the most deprived areas) could be well targeted.

The six selected multi-family residential buildings were chosen from one of the retrofitting projects carried out by Seville City Council within the Area of Concerted Rehabilitation due to their data availability. The information used for this work was provided by the Department of Social Services of Seville City Council (social workers conducted various interviews during the winter for the data collection). However, due to concerns regarding breaching data protection regulations, limited information was available. The situation of EP vulnerability of the six analysed residential buildings (a total of seventy-one households) has been evaluated both before and after an energy-efficiency intervention. It should be borne in mind that, since this work aims to identify those households in social housing that are most vulnerable to EP and that the available data was limited, all householders were assumed to be in the same monetary situation (below the monetary poverty threshold).

In contrast to the inability of current indicators to analyse vulnerability to EP, the application of the IVH has allowed the situation of EP vulnerability to be identified for the six selected residential buildings both before and after the intervention. The costs associated with EP imply significant social costs which are normally overlooked. In this respect, the contribution of this work is that it enables not only the cost associated with EP vulnerability to be estimated, but also the savings for the NHS, both in terms of the quality of life of the households. Additionally, it should be highlighted that the application of the IVH, unlike current EP indicators, indicates when low-income households are still vulnerable to EP after an energy-efficiency retrofitting because the situation of vulnerability is not only a matter of energy efficiency, but also of a lack of monetary resources that leaves the household unable to afford even minimum energy consumption.

With regards to policy implications, the costs of the energy-efficiency intervention were estimated for each project, as was the amortization period that depends on the level of reduced vulnerability. This analysis carries major implications for the development of energy policies since it allows the effectiveness of retrofitting projects to be evaluated, the social benefit of retrofitting programmes to be justified, and public funding to be more effectively deployed by Seville City Council. Furthermore, the methodology presented includes the calculation of the financial benefit in terms of a reduction of NHS expenses. All six projects assessed have a payback period of less than three years. In this context, this work shows that it is possible to include the NHS savings in a cost-benefit analysis of retrofitting projects, and those resources can be allocated towards providing financial support to low-income households, thereby further reducing vulnerability to EP (e.g., financing social subsidies for electricity and the social heating subsidies as defined in the National Strategy against Energy Poverty).

The limitations of this work include the limited availability of data for the analysis of as many factors as possible in a situation of vulnerability to EP and for the estimation of the cost associated to the NHS. In this respect, there are interesting challenges to be tackled: further applications need to be defined, and a comparative analysis should be performed on other Spanish regions with different socio-demographic characteristics and better data accessibility. Furthermore, this work provides evidence for the convenience of having complete local, regional, and national databases which ensure that no key EP factors are overlooked.

In conclusion, this work shows how the IVH would be able both to facilitate the development of a comprehensive and coordinated strategy in social housing to address EP, and monitor the ongoing project effectiveness in the city of Seville, in response to the National Strategy against Energy Poverty.

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References

[1] G. Semprini, R. Gulli, A. Ferrante, Deep regeneration vs shallow renovation to achieve nearly Zero Energy in existing buildings: Energy saving and economic impact of design solutions in the housing stock of Bologna, Energy and Buildings. 156 (2017) 327–342. doi:https://doi.org/10.1016/j.enbuild.2017.09.044.

[2] J.D. Healy, J.P. Clinch, Quantifying the severity of fuel poverty, its relationship with poor housing and reasons for non-investment in energy-saving measures in Ireland., Energy Policy 2004. 32 (2004) 207–220. http://econpapers.repec.org/RePEc:eee:enepol:v:32:y:2004:i:2:p:207-220 (accessed January 1, 2016).

[3] Directorate-General for Energy (European Commission), Clean energy for all Europeans, Brussels, 2019. https://publications.europa.eu/en/publication-detail/-/publication/b4e46873-7528-11e9-9f05-01aa75ed71a1/language-en?WT.mc_id=Searchresult&WT.ria_c=null&WT.ria_f=3608&WT.ria_ev=search.

[4] Anthony Threlfall, Understanding the costs and benefits of fuel poverty interventions: A pragmatic economic evaluation from Greater Manchester, Manchester, 2011.

[5] A. V Barker, A.A.V.B.B. A, M. Sc, D.M.S.P.G. Dip, Assessment of the Impact on Health and Health Costs due to Fuel Poverty in Bolton, Bolton, 2011.

[6] Department of Energy & Climate Change (DECC), Annual Fuel Poverty Statistics Report 2014, London, 2014.

[7] C. Sanchez-Guevara, M. Núñez Peiró, J. Taylor, A. Mavrogianni, J. Neila González, Assessing population vulnerability towards summer energy poverty: Case studies of Madrid and London, Energy and Buildings. 190 (2019) 132–143.

doi:https://doi.org/10.1016/j.enbuild.2019.02.024.

[8] H. Thomson, N. Simcock, S. Bouzarovski, S. Petrova, Energy poverty and indoor cooling: an overlooked issue in Europe, Energy and Buildings. (2019). doi:https://doi.org/10.1016/j.enbuild.2019.05.014.

[9] N. Shortt, J. Rugkasa, “The walls were so damp and cold” fuel poverty and ill health in Northern Ireland: results from a housing intervention., Health & Place. 13 (2007) 99–110. doi:10.1016/j.healthplace.2005.10.004.

[10] G.W. Evans, H. Saltzman, J.L. Cooperman, Housing Quality and Children’s Socioemotional Health, Environment and Behavior. 33 (2001) 389–399. doi:10.1177/00139160121973043.

[11] J. Rudge, R. Gilchrist, Measuring the health impact of temperatures in dwellings: Investigating excess winter morbidity and cold homes in the London Borough of Newham, Energy and Buildings. 39 (2007) 847–858. doi:https://doi.org/10.1016/j.enbuild.2007.02.007.

[12] G. Green, J. Gilbertson, Warm Front Better Health - Health Impact Evaluation of the Warm Front Scheme, Centre for Regional, Economic and Social Research. Sheffield Hallam University, 2008.

[13] D. Ormandy, V. Ezratty, Health and thermal comfort: From WHO guidance to housing strategies, Energy Policy. 49 (2012) 116–121. doi:10.1016/j.enpol.2011.09.003.

[14] K. Collins, Cold, cold housing and respiratory illnesses, in: N. Fergus, J. Rudge (Eds.), Cutting the Cost of Cold. Affordable Warmth for Healthier Homes, Taylor & Francis, London, 2000: p. 12.

[15] N. Pierse, R. Arnold, M. Keall, P. Howden-Chapman, J. Crane, M. Cunningham, Modelling the effects of low indoor temperatures on the lung function of children with asthma., Journal of Epidemiology and Community Health. 67 (2013) 918–925. doi:10.1136/jech-2013-202632.

[16] C. Liddell, C. Morris, Fuel poverty and human health: A review of recent evidence, Energy Policy 2010. 38 (2010) 2987–2997. doi:10.1016/j.enpol.2010.01.037.

[17] C. Robinson, S. Lindley, S. Bouzarovski, The Spatially Varying Components of Vulnerability to Energy Poverty, Annals of the American Association of Geographers. (2019) 1–20. doi:10.1080/24694452.2018.1562872.

[18] K. Primc, R. Slabe-Erker, B. Majcen, Constructing energy poverty profiles for an effective energy policy, Energy Policy. 128 (2019) 727–734. doi:https://doi.org/10.1016/j.enpol.2019.01.059.

[19] G. Besagni, M. Borgarello, The socio-demographic and geographical dimensions of fuel poverty in Italy, Energy Research & Social Science. 49 (2019) 192–203.

doi:https://doi.org/10.1016/j.erss.2018.11.007.

[20] H. Thomson, S. Thomas, E. Sellstrom, M. Petticrew, Housing improvements for health and associated socio-economic outcomes., The Cochrane Database of Systematic Reviews. 2 (2013). doi:10.1002/14651858.CD008657.pub2.

[21] H. Thomson, Housing improvements and their health effects, in: D. Braubach, M., Jacobs, D.E., Ormandy (Ed.), Environmental Burden of Disease Associated with Inadequate Housing. Methods for Quantifying Health Impacts of Selected Housing Risks in the WHO European Region, WHO Europe, WHO Regional Office for Europe, Copenhagen, 2011: pp. 179–195.

[22] L. Middlemiss, A critical analysis of the new politics of fuel poverty in England, Critical Social Policy. 37 (2016) 425–443.

[23] R. Castaño-Rosa, J. Solís-Guzmán, C. Rubio-Bellido, M. Marrero, Towards a multiple-indicator approach to Energy Poverty in the European Union: a review, Energy and Buildings. 193 (2019) 36–48. doi:https://doi.org/10.1016/j.enbuild.2019.03.039.

[24] European Commission, EU Energy Poverty Observatory (CN ENER/B3/SER/2015-507/SI2.742529), (2018). https://www.energypoverty.eu/ (accessed September 16, 2018).

[25] J.P. Gouveia, P. Palma, S.G. Simoes, Energy poverty vulnerability index: A multidimensional tool to identify hotspots for local action, Energy Reports. 5 (2019) 187–201. doi:https://doi.org/10.1016/j.egyr.2018.12.004.

[26] D. Bienvenido-Huertas, A. Pérez-Fargallo, R. Alvarado-Amador, C. Rubio-Bellido, Influence of climate on the creation of multilayer perceptrons to analyse the risk of fuel poverty, Energy and Buildings. 198 (2019) 38–60. doi:https://doi.org/10.1016/j.enbuild.2019.05.063.

[27] R. Marchand, A. Genovese, S.C.L. Koh, A. Brennan, Examining the relationship between energy poverty and measures of deprivation, Energy Policy. 130 (2019) 206–217. doi:https://doi.org/10.1016/j.enpol.2019.03.026.

[28] S.-N. Boemi, A.M. Papadopoulos, Energy poverty and energy efficiency improvements: A longitudinal approach of the Hellenic households, Energy and Buildings. 197 (2019) 242–250. doi:https://doi.org/10.1016/j.enbuild.2019.05.027.

[29] A. Kearns, E. Whitley, A. Curl, Occupant behaviour as a fourth driver of fuel poverty (aka warmth & energy deprivation), Energy Policy. 129 (2019) 1143–1155. doi:https://doi.org/10.1016/j.enpol.2019.03.023.

[30] N. Longhurst, T. Hargreaves, Emotions and fuel poverty: The lived experience of social housing tenants in the United Kingdom, Energy Research & Social Science. 56 (2019) 101207. doi:https://doi.org/10.1016/j.erss.2019.05.017.

[31] R. Listo, Gender myths in energy poverty literature: A Critical Discourse Analysis, Energy

Research & Social Science. 38 (2018) 9–18. doi:https://doi.org/10.1016/j.erss.2018.01.010.

[32] Spanish Government. Ministry for the Ecological Trasition, National Strategy against Energy Poverty 2019-2024 (Royal Decree 15/2018), Spain, 2019. https://www.miteco.gob.es/es/prensa/estrategianacionalcontralapobrezaenergetica2019-2024_tcm30-496282.pdf.

[33] O. Aristondo, E. Onaindia, Counting energy poverty in Spain between 2004 and 2015, Energy Policy. 113 (2018) 420–429. doi:https://doi.org/10.1016/j.enpol.2017.11.027.

[34] European Comission, European Union Statistics on Income and Living Conditions (EU-SILC), Eurostat. (2014).

[35] Spanish National Statistics Institute, Survey on Living Conditions (SLC)., Madrid, 2014.

[36] S. Tirado Herrero, J.L. López Fernández, P. Martín Gracía, Energy poverty in Spain. Employment generation potential derived from housing rehabilitation, 1ª, Madrid, 2012.

[37] J. Mendoza Aguilar, F.J. Ramos-Real, A.J. Ramírez-Díaz, Improving Indicators for Comparing Energy Poverty in the Canary Islands and Spain, Energies. 12 (2019). doi:10.3390/en12112135.

[38] C. Sánchez-Guevara Sánchez, F.J. Neila González, A. Hernández Aja, Energy poverty methodology based on minimal thermal habitability conditions for low income housing in Spain, Energy and Buildings. 169 (2018) 127–140. doi:https://doi.org/10.1016/j.enbuild.2018.03.038.

[39] S. Scarpellini, M.A.S. Hernández, J.M. Moneva, P. Portillo-Tarragona, M.E.L. Rodríguez, Measurement of spatial socioeconomic impact of energy poverty, Energy Policy. 124 (2019) 320–331. doi:https://doi.org/10.1016/j.enpol.2018.10.011.

[40] A. Sanz-Hernández, Social engagement and socio-genesis of energy poverty as a problem in Spain, Energy Policy. 124 (2019) 286–296. doi:https://doi.org/10.1016/j.enpol.2018.10.001.

[41] Andalusian Energy Agency. Ministry of Finance Industry and Energy, POVERTY project, “Renewable energies for vulnerable groups,” (n.d.). https://www.agenciaandaluzadelaenergia.es/es/conoce-la-agencia/la-agencia-en-el-exterior/proyectos-europeos/proyecto-powerty (accessed July 2, 2019).

[42] R. Castaño-Rosa, J. Solís-Guzmán, M. Marrero, A novel Index of Vulnerable Homes: Findings from application in Spain, Indoor and Built Environment. (2018) 1420326X18764783. doi:10.1177/1420326X18764783.

[43] M.R. Ruiz-Pérez, M.D. Alba-Rodríguez, R. Castaño-Rosa, J. Solís-Guzmán, M. Marrero, HEREVEA Tool for Economic and Environmental Impact Evaluation for Sustainable Planning Policy in Housing Renovation, Sustainability. 11 (2019).

doi:10.3390/su11102852.

[44] Eurostat, At-risk-of-poverty thresholds - EU-SILC survey., (n.d.). http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=ilc_li01&lang=en. (accessed December 26, 2018).

[45] Gobierno de España (Government of Spain), Real Decreto-ley 1/2013, de 25 de Enero, por el que se prorroga el programa de recualificación profesional de las personas que agoten su protección por desempleo y se adoptan otras medidas urgentes para el empleo y la protección social de las personas des, Boletín Oficial del Estado (BOE)., España, 2013.

[46] Spanish Government. Ministry for the Ecological Trasition, Insitute for the diversification and savings of energy, (n.d.). https://www.idae.es/en/articulos (accessed June 30, 2019).

[47] R.J. De Dear, G.S. Brager, Thermal comfort in naturally ventilated buildings: revision to ASHRAE standards 55, Energy and Buildings. 34 (2002) 549–561.

[48] BS/EN 15251:2007, Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics, London: BSI, 2007, n.d.

[49] B. van Hout, M.F. Janssen, Y.-S. Feng, T. Kohlmann, J. Busschbach, D. Golicki, A. Lloyd, L. Scalone, P. Kind, A.S. Pickard, Interim scoring for the EQ-5D-5L: mapping the EQ-5D-5L to EQ-5D-3L value sets, Value in Health : The Journal of the International Society for Pharmacoeconomics and Outcomes Research. 15 (2012) 708–15. doi:10.1016/j.jval.2012.02.008.

[50] R.R. Pinto JL, How much worth spending to win a year of quality-adjusted life? An empirical study, in: D.E. Puig-Junoy J, Pinto JL (Ed.), El Valor Monetario de La Salud., Springer-V, Barcelona, 2001: pp. 49–91.

[51] J. a. Sacristán, J. Oliva, J. Del Llano, L. Prieto, J.L. Pinto, What is an efficient health technology in Spain?, Gaceta Sanitaria 2002. 16 (n.d.) 334–343. doi:10.1016/S0213-9111(02)71933-X.

[52] Department of the Environment Transport and the Regions (DETR), Measuring Multiple Deprivation at the Small Area Level: The Indices of Deprivation 2000, London, 2000.

[53] Gobierno de España (Government of Spain), Real Decreto 106/2018, de 9 de marzo, por el que se regula el Plan Estatal de Vivienda 2018-2021, Boletín Oficial del Estado (BOE)., 2018.

[54] A. Hernández Aja, M. Vázquez Espí, C. García Madruga, Á. Matesanz Parellada, E. Moreno García, J. Alguacil Gómez, J. Camacho Gutiérrez, Análisis urbanístico de Barrios vulnerables (Urban analysis of vulnerable neighborhoods), Madrid, 2011. http://habitat.aq.upm.es/bbvv/bbvv.html (accessed July 6, 2019).

[55] S. Scarpellini, M.A. Sanz Hernández, E. Llera-Sastresa, J.A. Aranda, M.E. López Rodríguez, The mediating role of social workers in the implementation of regional policies targeting energy poverty, Energy Policy. 106 (2017) 367–375. doi:https://doi.org/10.1016/j.enpol.2017.03.068.

[56] S. Tirado Herrero, L. Jiménez Meneses, J.L. López Fernández, E. Perero Van Hove, V. Irigoyen Hidalgo, Energy Poverty in Spain. Towards a system of indicators and a state action strategy, 1ª, Madrid, 2018.

[57] Gobierno de España (Government of Spain), Real Decreto 2429/1979, de 6 de julio, por el que se aprueba la norma básica de edificación NBE-CT-79, sobre condiciones térmicas en los edificios., Boletín Oficial del Estado (BOE), España, 1979.

[58] Ministry of development, Analysis of the characteristics of residential buildings in Spain, (2011) 22. https://www.fomento.gob.es/areas-de-actividad/arquitectura-vivienda-y-suelo/urbanismo-y-politica-de-suelo/observatorio-de-la-vulnerabilidad-urbana/analisis-de-las-caracteristicas-de-la-edificacion-residencial-en-españa (accessed July 6, 2019).

[59] J. Ortiz, N. Casquero-Modrego, J. Salom, Health and related economic effects of residential energy retrofitting in Spain, Energy Policy. 130 (2019) 375–388. doi:https://doi.org/10.1016/j.enpol.2019.04.013.

[60] O. Aristondo, E. Onaindia, Inequality of energy poverty between groups in Spain, Energy. 153 (2018) 431–442. doi:https://doi.org/10.1016/j.energy.2018.04.029.

[61] R. Castaño-Rosa, C. Castro Fuertes, D. Alba Rodríguez, Estudio de rehabilitación de viviendas plurifamiliares del Casco Norte de Sevilla, University of Sevilla, 2012.

[62] EnergyPlus, EneryPlus 7.0. (2017). https://energyplus.net/ (accessed January 23, 2018).

[63] Institute for the diversification and saving of energy, User manual program energy rating of existing buildings CE3, Ministry of Industry, Energy and Tourism, Madrid, 2013.

[64] Institute for the diversification and saving of energy., Analysis of energy consumption in the residential sector in Spain, Seville, 2013.

[65] Instituto Valenciano de la Edificación, Building Typology Brochure Spain, TABULA Project, 2014.

[66] R. Castaño-Rosa, Module of Investments for Energy Efficiency of Buildings: Review and Application to Fuel Poverty Indicator, ETSIE, Seville, 2013.

[67] J.C. Romero, P. Linares, X. López, The policy implications of energy poverty indicators, Energy Policy. 115 (2018) 98–108. doi:https://doi.org/10.1016/j.enpol.2017.12.054.

[68] A. Peralta, L. Camprubí, M. Rodríguez-Sanz, X. Basagaña, C. Borrell, M. Marí-Dell'Olmo, Impact of energy efficiency interventions in public housing buildings on cold-related mortality: a case-crossover analysis, International Journal of Epidemiology. 46 (2017) 1192–1201. http://dx.doi.org/10.1093/ije/dyw335.

[69] D. Hernández, D. Phillips, Benefit or burden? Perceptions of energy efficiency efforts among low-income housing residents in New York City, Energy Research & Social Science. 8 (2015) 52–59. doi:https://doi.org/10.1016/j.erss.2015.04.010.

[70] Andalusia Statistics and Cartography Institute, Demographic data: City of Seville, (2018). https://www.juntadeandalucia.es/institutodeestadisticaycartografia/sima/ficha.htm?mun=41091 (accessed July 6, 2019).

[71] Spanish National Statistics Institute., Basic Demographic Indicators, (2018). http://www.ine.es/dyngs/INEbase/es/operacion.htm?c=Estadistica_C&cid=1254736177003&menu=ultiDatos&idp=1254735573002 (accessed July 6, 2019).

Annexe A

Table A1. Demographic data: Seville, Andalusia and Spain [56,70,71].

	Seville	*Andalusia*	*Spain*
Population by age group	Under age of 19: 19.91% 20-64: 60.97% 65 and over: 19.12%	Under age of 19: 24.49% 20-64: 60.75% 65 and over: 14.76%	Under age of 19: 22.93% 20-64: 60.90% 65 and over: 16.17%
Unemployment	20.93%	21.01%	13.06%
Unemployment benefit claimants	20.8%	26.30%	14.55%
Child poverty	38.6%	40.6%	28.3%
Household income (median)	15,166€	17,628€	19,668€
Household type	One person: 20% Couple: 38.8% Couple with children: 41.2%	One person: 32.7% Couple: 27.8% Couple with children: 39.5%	One person: 25.2% Couple: 35.5% Couple with children: 39.3%
Age of dwelling	Pre-1919: 27.7% 1919-1944: 11.4% 1945-1964: 3.0%	Pre-1919: 19.3% 1919-1944: 21.6% 1945-1964: 14.4%	Pre-1919: 21.2% 1919-1944: 16.1% 1945-1964: 18.9%
Tenure	53% social rented sector 47% private sector	29% social rented sector 71% private sector	13.2% social rented sector 80% private sector
Fuel poverty rate (2M indicator)	13.0%	18%	17%

Table A2. Composition of survey used for the data collection (Source: Authors' own based on the information provided by the Department of Social Services).

Energy poverty experience: household characteristics
• Number of members in the household • Income of the household per month • Housing cost per month (rent or mortgage) • Taxes paid per month

- Benefits received (Bereavement allowance, Child benefits, Disability living allowance, Unemployment allowance, Housing benefit, Incapacity benefit, Income support, etc.)
- Additional health expenditure per month (expenditure on disabled relative, medicine expenditure, etc.)
- Tenure (owner, private, or social renter)
- How does the household manage to pay for heat and electricity?
- Does the household have difficulties paying its gas and/or electricity bills?
- Does the household feel ashamed talking to friend/relatives about any problem related to gas or electricity bills?
- How does the household perceive its state of health according to usual activities, pain, discomfort, anxiety, and depression? Slight, moderate, severe, or extreme problems.

Technical inspection: building characteristics

- Fuel used for heat
- Type of heating and hot water systems
- Insulation in roof, ground floor, and/or walls
- Type of windows (single glazing, double glazing and/or low-emission double-glazing)
- Type of retrofit improvements installed

Table A3. Main pathologies found during the technical inspection and consequences for householders' state of health (Source: Authors' own).

Cause	*Consequences*
Cold indoor environment	Risk of suffering cardiovascular diseases, colds and other respiratory illnesses. Risk of suffering psychological symptoms, such as lack of motivation and a sense of inability. Households with respiratory tract infections, viral diseases, and wheezing.
Permanent presence of mould	Reduction of social activities due to the shame of inviting friends home. Increase in social isolation. Households with allergic symptoms and asthma. Evidence of fatigue, headache, rhinitis, sore throat, and dermal symptoms.
Reduction in households' food expenditure during colder periods	Reduction in households' caloric intake. Negative effects on educational achievement of children and poor job attainment of parents.