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Transferring the Index of Vulnerable Homes: application at the local-scale in England to assess fuel poverty vulnerability

Raúl Castaño-Rosa (corresponding author), Department of Building Construction II, University of Seville, Avenue Reina Mercedes, 4-a 41012, Seville, Spain. Email: raulcastano90@gmail.com.

Graeme Sherriff, Sustainable Housing & Urban Studies Unit, University of Salford, Salford, UK.

Harriet Thomson, School of Social Policy, University of Birmingham, Birmingham, UK.

Jaime Solís Guzmán, Department of Building Construction II, University of Seville, Spain.

Madelyn Marrero, Department of Building Construction II, University of Seville, Spain.

Abstract

Fuel poverty, or energy poverty, has traditionally been associated with households that cannot afford to keep their homes adequately warm and/or cool due to low income and energy inefficient dwellings. Recent studies show a need for a good understanding of levels of vulnerability and how they are shaped by poor quality housing and economic circumstances. This work, which examines the current level of vulnerability to fuel poverty in a neighbourhood in the Broughton ward of Salford using quantitative data, provides a comprehensive tool to assess fuel poverty vulnerability at a local scale in England, the Index of Vulnerable Homes (IVH), which evaluates the identification of households in or at risk of fuel poverty. The IVH results lead to an evaluation of current fuel poverty indicators in terms of their ability to assess fuel poverty vulnerability in England, providing a fuller understanding of the variety of fuel poverty situations, as well as recognizing the high prevalence of hidden fuel poverty. Additionally, having used the IVH in both England and Spain, it makes possible reflections upon how vulnerability to fuel poverty may differ in these countries, leading to relevant recommendations for policymakers to develop effective fuel poverty measures.

Keywords

Vulnerable households, energy efficiency, energy poverty, fuel poverty, health, thermal comfort

Highlights

- The size and type of household is a key factor in vulnerability to fuel poverty.
- Current monitoring indicators fail to recognise hidden fuel poverty.
- Assessment of thermal comfort helps to understand the seasonality of vulnerability.

1. Introduction

The term fuel poverty, or energy poverty, has been considered as a manifestation of domestic energy deprivation or energy vulnerability, and has been included in a number of EU policy proposals [1]. It is important to note that although many academic books and journal papers use the concepts of energy poverty (EP) and fuel poverty (FP) with different meanings [2,3], in general the terms EP and FP can be used interchangeably [3] and generally understood as the inability to achieve a socially and materially sufficient level of domestic energy services [4] or the inability of particular households to achieve the minimum energy services necessary to have an acceptable and healthy life [5]. Henceforth this paper refers to FP, understood within this broad conceptualisation.

FP has traditionally been associated with countries with lengthy and cold winters, but it is also known that in countries with hot summers households can have high summer energy consumption [6] and there is increasing interest in the relationship between FP and hot temperatures [7]. The effectiveness of many FP policies is limited by difficulties in targeting households. Two main issues can be identified: 'exclusion inaccuracies', whereby households that would benefit are not recognised by policy and therefore not supported; and 'inclusion inaccuracies', whereby households that are not experiencing FP but meet the eligibility criteria are awarded support [8]. As a result, there is a risk that those households in greatest need are missed, public money is not best deployed, and FP resources are not distributed effectively. The different composition of demographic groups, the scope of the problem, and the variety of types of indicators used to measure FP are the main challenges [9].

Many indicators and definitions of FP have been developed in countries across the EU, for instance Ireland, Slovakia, France and the UK all have official frameworks [10], and numerous studies have developed methodologies to analyse consumers at risk of being in a FP situation, e.g. [11–14]. However, few empirical studies have explored the relationship between FP, thermal comfort, and the effect of living in an inadequately heated dwelling [15]. Furthermore, no official definition or measure has been implemented across the EU – although the recently adopted Clean Energy Package legislation [16] includes indicative guidance. The difficulty of understanding the composition and characteristics of FP, identifying which households are most in need of support, and the differences in drivers across countries are key challenges to the creation of a common standard [17,18].

Another aspect of understanding FP is the identification of its health impacts. Well-established literature indicates that living in cold and/or damp housing conditions has significant implications for both morbidity and excess winter mortality [19–21]. In addition, FP has been linked to adverse psychological symptoms, food insecurity, and poor educational attainment in children [22–25]. In this context, we consider it essential to study the relationship between thermal comfort and household health, especially when the mortality risk of households living in a cold house can be reduced by over 70% by increasing the indoor temperature to WHO (World Health Organization) levels (21°C in living rooms and 18°C in bedrooms) [26].

A good understanding of levels of vulnerability and how they are shaped by poor quality housing and economic circumstances, as well as an appreciation of which measures are most appropriate in which setting, is therefore essential for policymakers to be able to most effectively target FP alleviation measures [27].

In this study, the Index of Vulnerable Homes (IVH) [28] has been adapted to the English context and applied to an inner-city area of the Broughton ward, Salford, in order to evaluate the identification of households in or at risk of FP. To this end, three different types of households, representing those households with the highest rates of FP in England, have been considered. Additionally, a comparative analysis with the 10% and LIHC indicators, both of which have been used for official statistics on FP in UK [29], has been undertaken. This leads to an understanding of the advantages and disadvantages of current FP indicators in terms of their ability to assess vulnerability to FP. Finally, analysis of the IVH results from its application in both England and Spain provides some relevant reflections upon how FP vulnerability may differ between these contexts.

2. Description and methodology of the study

This work uses case study design and quantitative data to examine the current level of FP vulnerability in an inner-city area of the Broughton ward, Salford, by applying the IVH [28], identifying and assessing not only those households experiencing FP but also those vulnerable to experiencing it. Furthermore, a comparative analysis with the 10% and the LIHC indicators highlights the advantages and disadvantages of both indicators in terms of their ability to assess vulnerability to FP. The IVH was originally developed within the Spanish context and its four main components must therefore be adapted for this UK study: Monetary Poverty Indicator (MPI), Energy Indicator (EnI), Comfort Indicator (CI), and Health-Related Quality-Life Cost (HRQLC).

MPI (Monetary Poverty Indicator): It assesses the monetary vulnerability of the household on the basis of household net income. Monetary Poverty and Severe Monetary Poverty Thresholds (MPT and SMPT) are set according to the economic situation in the studied area (England), and the size and composition of the households (expressed with the modified scale provided by the Organization for Economic Co-operation and Development (OECD)) [30]). This allows us to define a more precarious level of monetary poverty, identify those households with the lowest disposable incomes and, consequently, improve current FP indicators. 60% and 40% of the median equivalised disposable income for one person in the UK in 2016, according to Eurostat statistics [31], was used as the MPT and SMPT respectively. This process is further explained by Castaño et al. [28]. Table 1 shows the thresholds set for the UK.

Table 1. Monetary thresholds for the UK. Disposable income per person. (Source: Authors' own analysis).

Household	MPT	SMPT
One adult	£10,393	£6928
Two adults	£15,590	£10,392
Two adults and one child	£18,707	£12,470
Two adults and two children	£21,825	£14,549
Two adults and three children	£24,943	£16,627

The MPI is defined using equation (1):

$$MPI = NI / T \qquad (1)$$

where NI is net income (calculated by subtracting housing expenditure (rent, mortgage, healthcare expenditure, etc.) and water and municipal solid waste management expenditure from the household gross income); T is poverty threshold. A household is said to be in monetary poverty or severe monetary poverty if its net income falls below the set threshold (MPI < 1.00).

EnI (Energy Indicator): The energy vulnerability of a household is assessed according to required energy consumption. The energy analysis is conducted by setting the energy threshold to the median energy consumption required (energy demand) by the type of dwelling in the case study. The EnI is defined using equation (2):

$$EnI = EC / MEC \qquad (2)$$

where EC is energy consumption required (modelled demand) and MEC is the median energy consumption required (energy demand) for the type of building in the study area. Using modelled demand avoids either inclusion effect, where households with an inadequate use of systems (and high energy consumption) are fuel poor, or exclusion effect, where households with low energy consumption because they cannot afford a minimum energy consumption are not in FP (hidden fuel poverty). Furthermore, this prevents the influence of the characteristics, priorities and customs of households on the energy evaluation. Therefore, the housing energy consumption is adequate if it is below the energy threshold, or "admissible" (EnI < 1.00), otherwise it is considered "inadmissible" (EnI > 1.00).

CI (Comfort Indicator): The analysis of FP in relation to thermal comfort has traditionally been conducted by using single self-reported indicators, such as the European Union Survey on Income and Living Conditions (EU-SILC) [32]. As a novel aspect in the analysis of FP in relation to thermal comfort, the CI instead uses the adaptive-thermal comfort model defined in the normative EN 15251:2007 [33]. The thermal-comfort analysis is carried out by using the percentage of hours that living spaces fall outside the set comfort range. 80% of all hours in thermal-comfort is used as the comfort threshold, meaning that occupants may be determined thermally uncomfortable for 5 hours per day, considered to be sleeping hours [34]. Category I, the most stringent criteria (comfortable-temperature range between 21.0 °C – 25.5 °C), for the living room, and Category III, a wide comfortable-temperature range (comfortable-temperature range between 18.0 °C – 27.0 °C), for bedrooms, are used to define the different thermal-comfort ranges according to the normative EN 15251:2007 [33]. Note that these criteria follow with the WHO recommendation of a minimum temperature of 21.0 °C in living rooms and 18.0 °C in all other rooms [26]. Therefore, households will be thermally uncomfortable, the CI result is "inadmissible", if the percentage of hours fall below the comfort range (CI <80%), otherwise the CI result is "admissible" (CI >80%).

HRQLC (Health-Related Quality-Life Cost): This is another relevant aspect; the possibility of providing the costs associated to FP vulnerability. The HRQLC allows for conducting an economic analysis of a vulnerable situation, and is defined by ascribing a range of monetary values to the Quality-Adjusted Life Year (QALY) [35] defined for each level of vulnerability. The QALY is a traditional measure to assess people's state of health on the basis of 5 different levels of health according to 5 dimensions (Mobility, Self-care, Usual activities, Pain/Discomfort, and Anxiety/Depression) by using the EQ-5D-5L Index Value Calculator [36]. The cost-effectiveness value of a human life, set between £30,000 – 35,000 for over 7 years by the National

Institute for Health and Care Excellence (NICE), was used to assign the HRQLC for each of the thirteen vulnerability levels of the IVH in England. The process behind this is explained further by Castaño et al. [28]. Note that the QALY and HRQLC are different depending on the analysed country, and therefore must be re-calculated for each country where the IVH is applied.

Table 2 shows the IVH adapted to the British context: monetary poverty, energy and comfort indicators, QALYs and HRQLC.

Table 2. The IVH's levels of vulnerability adapted to the British context (Source: Authors' own).

Level	Variables			QALY	HRQLC (£)
1	MPI: NMP	EnI: Admissible	CI: Inadmissible	0.837	4890
2	MPI: NMP	EnI: Inadmissible	CI: Admissible	0.768	6990
3	MPI: NMP	EnI: Inadmissible	CI: Inadmissible	0.725	8250
4	MPI: MP	EnI: Admissible	CI: Admissible	0.721	8370
5	MPI: MP	EnI: Admissible	CI: Inadmissible	0.689	9330
6	MPI: SMP	EnI: Admissible	CI: Admissible	0.602	11,940
7	MPI: MP	EnI: Inadmissible	CI: Admissible	0.585	12,450
8	MPI: MP	EnI: Inadmissible	CI: Inadmissible	0.478	15,660
9	MPI: SMP	EnI: Admissible	CI: Inadmissible	0.312	20,640
10	MPI: SMP	EnI: Inadmissible	CI: Admissible	0.212	23,640
11	MPI: SMP	EnI: Inadmissible	CI: Inadmissible	-0.158	34,740
12	MPI: MP	EnI: Inadmissible*	CI: Inadmissible	-0.215	36,450
13	MPI: SMP	EnI: Inadmissible*	CI: Inadmissible	-0.337	40,110

* The household cannot afford a minimum energy consumption due to a lack of monetary resources.

NMP: No monetary poverty; MP: monetary poverty; SMP: severe monetary poverty.

2.1. Case study area

In the UK, social deprivation and health are well documented using deprivation indices [37,38]. The Index of Multiple Deprivation (IMD) [39], one of the most widely used deprivation indices for research and funding decisions at the ward and district-level, provides a set of relative measures of deprivation for small areas (Lower-layer Super Output Areas) across England. This study uses this indicator as the basis for targeting and analysing a small area in a very vulnerable situation, mainly underpinned by the relationship between deprivation and FP [40], as well as its correlation with mortality and morbidity [41]. Broughton is Salford's second largest ward by population. According to the Low Income High Cost (LIHC) indicator, it has a higher rate of FP (13%) in comparison with Salford and England (9.5% and 11.0%), and is in the most deprived decile of the IMD [38]. 102 households in the Broughton ward were selected for this study, having been chosen at random from the Energy Performance Certificate (EPC) database. It is worth noting that, although not all residents of deprived areas are deprived, and not all deprived people live in deprived areas, there is some remarkable correspondence to the spatial patterns [42]. As explained above, the strong relationship amongst area deprivation, FP, mortality, and morbidity, underpin the selection of this ward for this study.

2.1.1. Characteristics of dwellings

The archetypal housing type in our case study area is pre-1919 terraced housing (it represents 25.2% of the housing stock in England [43]). Data from energy performance certificates [44] and the Typology Approach for Building Stock Energy Assessment (TABULA) project [45], have been used to define the characteristics of the dwellings within the area of study. The DesignBuilder software [46] combined with the dynamic thermal-comfort software EnergyPlus 7.0 [47], has been used to simulate one year of operation and indoor temperature. This allows the required energy consumption (modelled demand) applied to all end uses of the dwelling to be calculated.

Two types of dwellings exist in the sample analysed depending on the floor area, 62 m^2 and 119 m^2, and the EPC rating, score 35 (band F) and score 15 (band G). Tables 3 and 4 describe the dwelling construction and the characteristics of dwelling systems.

Table 3. Description of dwelling construction (Pre-1919 terraced house) [45].

Element	Description	U-values (W/m^2K)
Walls	Solid brick, as built, no insulation	2.10
Roof	Pitched without insulation	2.30
Floor	Reinforced concrete raft with no insulation added	0.81
Ground floor	Suspended timber above a ventilated underfloor void	1.50
Windows	Double glazed windows in wooden frames	4.80
Doors	Wooden door with frames of similar material	3.00
Party wall	Same as external walls	1.97

Table 4. Characteristics of dwelling systems [44].

Floor area (m^2)	EPC rating	System	Description
62	35 (F)	Heating	Room heaters, mains gas
		Domestic hot water	Gas instantaneous at the point of use
		Others	Electricity
119	15 (G)	Heating	Portable electric heaters for most rooms
		Domestic hot water	Electric instantaneous equipment at the point of use
		Others	Electricity

The heating pattern and the operational parameters were set to calculate the energy consumption required by the analysed dwellings. The heating pattern during the simulation was set according to the times set out in the SAP guidance issued by BRE Group (from 7 am until 9 am in the morning and 4 pm until 11 pm in the evening) [48]. Table 5 shows the operational parameters established for each room type. It was taken into account that householders could spend most of their time at home and it was recognised that vulnerable householders, who spend a substantial part of their time at home, for instance unemployed, students, or severely disabled people, may need special consideration.

Table 5. Occupancy profile used in the simulation.

Room occupied	Monday to Friday (Times of the day)	Saturday and Sunday (Times of the day)
Living Room	9am – 12pm; 1pm – 6pm; 7pm – 11pm	10am – 12pm; 1pm – 6pm; 7pm – 11pm
Kitchen and Dinning	8am – 9am; 12pm – 1pm; 6pm – 7pm	9am – 10am; 12pm – 1pm; 6pm – 7pm
Bedroom 1	11pm – 8am	11pm – 9am

The required energy consumption (modelled demand) of the analysed dwellings depending on the floor area and the EPC rating from the modelling simulation of the typologies was defined as 32,604 kWh/year and 60,095 kWh/year for dwellings with 62 m^2 and 119 m^2 respectively. In comparison with most other European countries, the UK housing stock is relatively old and has poor insulation. Consequently, households have additional energy consumption to maintain a comfortable level of thermal comfort. Latest data on domestic energy consumption in the UK shows a decrease in the energy demand from 2016 due to the gradual improvement of housing stock to more energy efficient houses, leading currently to a median energy consumption (energy demand) of 40,116 kWh/year [49]. In this sense, a combination of energy-efficiency measures, the most common combination according to the National Efficiency Data-Framework (NEED) project [50], is proposed, assessing the impact of an energy-efficiency intervention on FP vulnerability reduction.

2.1.2. Characteristics of households

This work aims to provide an analysis at the local level that incorporates regional diversity of income levels, resource availability and socioeconomic characteristics of residents living in FP vulnerability. To this end, three different types of households, which represent the standard households with the highest rates of FP in England [29], were defined. The main data sources used to define each household were the English Housing Survey (EHS), which collects household-level information on housing circumstances and is used for official statistics on FP in England [43,51,52], and the Annual Fuel Poverty Statistics Report [29]. Table 6 summarizes the three analysed households according to household size (within the case study area, 48 households contain one adult, 25 two adults, and 29 two adults with one child) [53], housing cost depending on the household's composition (median housing cost for owners representing the most common tenure in England) [29], income (income distribution by decile after tax within the range 1^{st} – 7^{th} is analysed for each household size) [54], tenure (43% of households in FP are the owner, while just 20% are privately rented. Then owner is the typology of tenure analysed for each household size) [29], and water and sewerage bill (average annual water and sewerage charges in England) [55].

Table 6. Characteristics of analysed households.

Household size	Housing cost (£/year)	Income (£/year)	Tenure	Water and sewerage bill (£/year)
1.- Households with one adult (n=48)	5247	Deciles 1^{st} to 7^{th} after tax	Owner	395
2.- Households with two adults (n=25)	7102			
3.- Households with two adults and one child (n=29)	7950			

"n" represents the number of households within the case study area.

3. Results and discussion

This section presents the analysis from the application of the IVH to the households in the selected area (section 3.1). In addition, the impact of an energy-efficiency intervention on the dwelling, with the intention of addressing the level of vulnerability to FP, has been assessed (section 3.2). Finally, a comparative analysis with the 10% and LIHC indicators, which have been used for official statistics on FP in UK [29], has been made in section 3.3.

3.1. Evaluation of the level of vulnerability

After setting out the British context and defining the proposed case study area, this section presents results from the application of the IVH. The first step is to define the thresholds for the variables.

MPI (Monetary Poverty Indicator): According to Table 1 the MPT is set at £10,393 for household type 1 (one adult), £15,590 for household type 2 (two adults) and £18,707 for household type 3 (two adults and one child). The SMPT is set at £6,928 for household type 1, £10,392 for household type 2 and £12,470 for household type 3. The following Table 7 shows the MPI status for each of household types defined in Table 6.

Table 7. Results of the MPI depending on the type of household.

Household size	Income decile	MPI
1.- One adult	1st	Severe monetary poverty
	2nd-3rd	Monetary poverty
	4th-7th	No poverty
2.- Two adults	1st-4th	Severe monetary poverty
	5th-6th	Monetary poverty
	7th	No poverty
3.- Two adults and one child	1st-5th	Severe monetary poverty
	6th	Monetary poverty

7th	No poverty

EnI (Energy Indicator): The energy threshold is set at the median energy consumption required (energy demand) by the type of dwelling - pre-1919 terraced house - in the case study, as obtained from the annual fuel poverty statistics in the UK [29]: 13,793 kWh/year and 25,648 kWh/year for dwellings with 62 m^2 and 119 m^2 respectively. The housing energy consumption is adequate if it is below the energy threshold, or "admissible" (EnI < 1.00), otherwise it is considered "inadmissible" (EnI > 1.00). Table 8 shows EnI results depending on the characteristics of dwellings analysed.

Table 8. Results of the EnI depending on the characteristics of dwellings.

Floor area (m^2)	Total energy consumption (kWh/year)	Energy consumption threshold (kWh/year)	EnI
62	32,604	13,793	Inadmissible
119	60,095	25,648	Inadmissible

The Buildings Performance Institute Europe (BPIE) considers old and inefficient residential buildings as those where energy demand exceeds 200 kWh/m^2 [56], and this underpins this result for the analysed dwellings (494 kWh/m^2 and 505 kWh/m^2 for dwellings with 62 m^2 and 119 m^2, respectively).

CI (Comfort Indicator): According to the explanation given in section 2, the comfort threshold has been set at 80% of the hours in which the living areas must be within the thermal comfort ranges. After analysing the number of hours in thermal comfort from the modelling simulation, the CI is "admissible" during summer (CI > 80%) but "inadmissible" during winter, spring and autumn (CI < 80%).

Table 9 shows the vulnerable situation of three types of households who are living in a pre-1919 terraced house in the analysed area of the Broughton ward of Salford.

Table 9. Results of the IVH application.

Household size	Income decile	Season	IVH	HRQLC* (£/year)
1. Households with one adult (n=48)	1st (SMP)	Summer	10	1,534,320

		Remainder	11	
	2nd-3rd (MP)	Summer	7	713,184
		Remainder	8	
	4th-7th (NP)	Summer	2	380,544
		Remainder	3	
2. Households with two adults (n=25)	1st-4th (SMP)	Summer	10	799,125
		Remainder	11	
	5th-6th (MP)	Summer	7	371,450
		Remainder	8	
	7th (NP)	Summer	2	198,200
		Remainder	3	
3. Households with two adults and one child (n=29)	1st-5th (SMP)	Summer	10	926,985
		Remainder	11	
	6th (MP)	Summer	7	430,882
		Remainder	8	
	7th (NP)	Summer	2	229,912
		Remainder	3	

*HRQLC represents total cost the National Health Service (NHS) has per life year saved of those households living in the analysed area.

SMP: Severe Monetary Poverty; MP: Monetary Poverty; NP: No Poverty; n: number of households.

The main conclusion from Table 9 is that the analysis of the different household typologies highlights the importance of the size and type of household in a situation of vulnerability to FP. This result reinforces the fact that, assuming household income is constant, the larger the size of the household, the greater the vulnerability of the home [57]. Recent fuel poverty statistics support this result, where the average fuel poverty gap for one adult is among the lowest at £291, with multi-person households seeing the highest at £493 [29].

3.2. Dwelling improvement: energy-efficiency intervention

In this section, an energy-efficiency intervention, which can be defined as a procedure to renew or change systems, dwelling fabric or use of controls to improve the energy performance of homes [58], is assessed in relation to the IVH, showing how owners and housing providers could reduce current vulnerability and improve households' quality of life.

The proposed intervention consists of installing a combination of energy-efficiency measures: solid wall insulation, loft insulation, and UPVC (unplasticized polyvinyl chloride) double glazing windows, representing the most common combination of energy-efficiency measures used in England according to the National Efficiency Data-Framework (NEED) project [50]. The required energy consumption (modelled demand) of the dwellings after the energy-efficiency intervention has been obtained by using the energy modelling package SAP, currently the tool used to predict energy consumption for new build properties in England [48]. Note that the new dwelling configurations would have associated SAP values of 59 and 55 (band D) improving the initial EPC rating from F and G to D. The energy consumption (modelled demand) of the dwellings would also be reduced to 10,664 kWh/year and 23,562 kWh/year for dwellings with 62 m^2 and 119 m^2 of floor area. Taking these values into account the results of the EnI after installing the selected combination of energy-efficiency measures are "admissible" in both cases.

The thermal comfort analysis after the energy-efficiency intervention, which was obtained from the dynamic thermal simulation of the new dwelling configurations in the modelling software, shows that the percentage of hours in thermal comfort would be increased after the energy-efficiency intervention in all living spaces, leading to the home becoming comfortable in spring (CI > 80%). The CI is then "admissible" during summer and spring (CI > 80%). The CI is however "inadmissible" during winter and autumn (CI < 80%).

The following Table 10 shows the IVH results after the energy-efficiency intervention and shows the reduction in the level of FP vulnerability, the improvement of household health, and the potential savings to the NHS. Note that the MPI has not changed from the initial stage, as the monetary poverty situation of the household (social aspect) has remained the same: only the technical characteristics of dwellings have changed.

Table 10. Results of the IVH application after (& before) the energy-efficiency intervention.

Household size	Income decile	Season	IVH	HRQLC* (£/year)
1. Households with one adult (n=48)	1st (SMP)	Su & Sp	6 (10)	781,920
		W & A	9 (11)	(1,534,320)
	2nd-3rd (MP)	Su & Sp	4 (7)	424,800
		W & A	5 (8)	(713,184)
	4th-7th (NP)	Su & Sp	- (2)	117,360
		W & A	1 (3)	(380,544)
2. Households with two adults (n=25)	1st-4th (SMP)	Su & Sp	6 (10)	407,250
		W & A	9 (11)	(799,125)
	5th-6th (MP)	Su & Sp	4 (7)	221,250
		W & A	5 (8)	(371,450)
	7th (NP)	Su & Sp	- (2)	61,125
		W & A	1 (3)	(198,200)
3. Households with two adults and one child (n=29)	1st-5th (SMP)	Su & Sp	6 (10)	472,410
		W & A	9 (11)	(926,985)
	6th (MP)	Su & Sp	4 (7)	256,650
		W & A	5 (8)	(430,882)
	7th (NP)	Su & Sp	- (2)	70,905
		W & A	1 (3)	(229,912)

*HRQLC represents total cost the NHS has per life year saved of those households living in the analysed area.

Su: summer; Sp: Spring; W: Winter; A: Autumn; SMP: Severe Monetary Poverty; MP: Monetary Poverty; NP: No poverty; n: number of householders. (brackets): results before the EE intervention.

These results highlight that the higher income deciles would not have a vulnerable situation in summer and spring after the energy-efficiency intervention, and would have only a level 1 of vulnerability in winter and autumn. Furthermore, it is important to highlight that a comfortable situation would be achieved in spring, leading the initial level of vulnerability in spring to be reduced. The results also reaffirm the fact that the larger the household, the more difficult it is to reduce the level of vulnerability. Note that although the energy efficiency of the dwelling would have been improved considerably, and households would be living in a more energy efficient house with a lower energy demand, the mental and physical stresses related to living in monetary poverty are likely to persist and these relate not only to energy but also to other aspects of household life such as diet and socialising. This analysis implies the possibility of revising the current eligibility criteria for FP financial benefits and ensuring that vulnerable consumers will be able to afford a minimum level of energy consumption after the intervention.

3.3. Comparative analysis with the 10% and LIHC indicators

To show the practical consequences of this work as well as evidence of how it could help to assess vulnerability to FP in England, a comparative analysis with current FP indicators (10% and LIHC) in terms of their ability to assess vulnerability to FP has been conducted (Figure 1).

LIHC indicator: This measure defines FP as when "*the household income is lower than the poverty threshold and their energy expenditure is higher than the median threshold*" [59]. According to this definition and the latest FP statistics, it can be deduced that those households who cannot pay their energy bill, because of a lack of monetary resources but who live in an energy efficient dwelling after an energy-efficiency intervention would not be considered to be fuel poor. In this example, this would apply to households with one adult within the 1^{st} income decile, two adults within the 1^{st} – 4^{th} income deciles, and two adults and one child within the 1^{st} – 5^{th} income deciles in Table 10. Despite this lack of recognition the household may still experience poverty and have to make difficult decisions characterised by the "heating or eating" [24] dilemma. It could therefore be said that they are in hidden fuel poverty (HFP) [60] (levels 4 – 6 and 12 – 13 of the IVH, in Figure 1). This implies an exclusion effect, or false negative, where a household is not fuel poor by official measurements but nonetheless experiences poverty relating to energy.

A recent critical analysis by Middlemiss [61] argues that the LIHC obscures the effect of energy prices on levels of FP and tends to overemphasise the role of energy-efficiency improvements in its alleviation. The IVH responds to this by recognising that a household can continue to experience poverty after energy-efficiency improvements have taken place and by helping to identify the particular aspect (monetary resources or technical characteristics) needing to be addressed.

10% indicator: According to this measure a household is in FP when it does not "have adequate energy services for 10 per cent of income" [57]. Whilst England stopped using this indicator in 2013, the remaining devolved nations of the UK continued to make use of the 10% indicator. The most notable weakness of this indicator is that those households who have a high energy consumption but are not poor would nevertheless be recognised as fuel poor. In this study this would apply to households with one adult within the 4^{th} – 7^{th} income deciles and multi-person households within the 7^{th} income decile in Table 10 and leading to a higher rate of households being found to be fuel poor (levels 1 – 3 of the IVH, see Figure 1 for detail). This is an inclusion effect, or false positive, in that households that are not experiencing poverty are captured by the indicator. Furthermore, this indicator presents similar challenges, as does the LIHC indicator, when analysing the real improvement for households after an energy-efficiency intervention: it would exclude households who are monetary poor, but are living in an energy efficient dwelling.

The following Figure 1 compares results from the MPI and EI with expected results from the 10% and LIHC indicator for each level of vulnerability. It shows a graphical comparative analysis of the IVH with the 10% and LIHC indicators, in addition to representing the HFP and "heating or eating" effect within the IVH, it highlights how the previous FP indicators do not take it into consideration. For example, it illustrates that levels 1 – 3 correspond to potential false positives when using the 10% measure and that levels 4 – 6 and levels 12 – 13 correspond to potential false negatives when using the LIHC measure. Note that only levels 7 – 11 would overlap with both 10% and LIHC indicators recognising those households in FP.

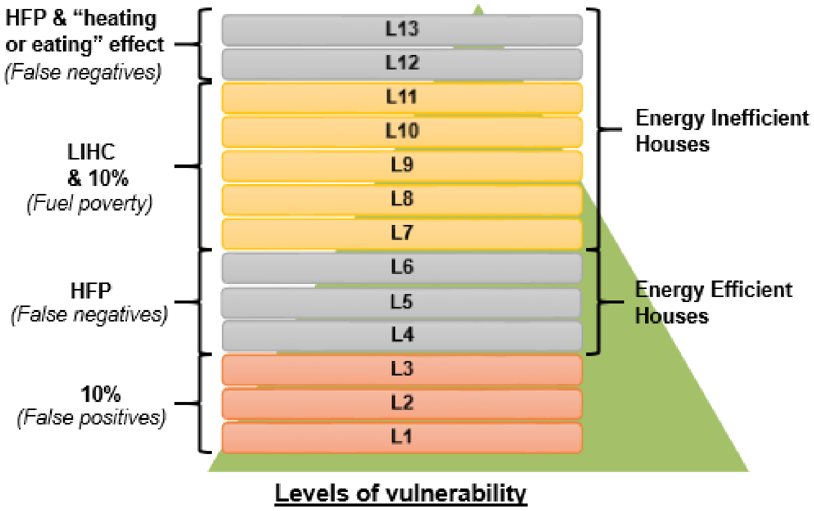

Figure 1. Comparative analysis: IVH, LIHC, 10%, HFP and "heating or eating" effect.

This comparative analysis exposes limitations of the LIHC and 10% indicators and demonstrates that they create false negatives and false positives when applied across England. It also suggests that HFP and the "heating or eating" effect would not be recognised under either indicator. The IVH therefore has the potential to reduce these two main inaccuracies discussed above - exclusion and inclusion. This work shows how housing providers in Salford could help households vulnerable to FP to pay their energy bills by making effective use of current financial benefits for vulnerable households during winter in England, for instance Winter Fuel Payments [62], Cold Weather Payments [63] and Warm Home Discount [64]. Note that, unlike the IVH, neither the LIHC and 10% indicators provide an economic analysis of the level of vulnerability to FP, and the IVH is therefore better able to estimate savings and costs to the NHS.

Additionally, according to the previous application of the IVH in Spain [28], it is possible to reflect upon how the Spanish and British contexts may differ. For example, these results reveal and provide a way of analysing the impact that climatologic factors of the studied area have on levels of vulnerability. The first case study, set in the south of Spain, showed a higher level of vulnerability during winter, which is a relatively short period of cold weather, while this case study in England reveals a greater level of vulnerability in spring, winter and autumn, a longer cold period. As a result, the energy-efficiency measures recommended in the Spanish case study were aimed at a reduction of energy consumption in hot seasons, while the British case study focuses on reducing the energy consumption for heating in cold seasons.

It is important to note that some limitations can be noted in relation to the application of the IVH in other countries. These relate to the data requirements, for instance the MPI will require the adaptation of the MPT and SMPT (set in accordance with Eurostat statistics for European countries); the EnI will require the adaptation of the MEC (set according to data availability on median energy consumption required for the housing sector); and the CI will require the adaptation of the thermal comfort range (the UNE EN 15251:2007 [33] that may be used in European countries, and the adaptive model ASHRAE 55-2010 [65] for the others). Furthermore, the HRQLC will require the monetary value placed on human life to ascribe to a QALY (set by the National Health Service in this, UK, context). Additionally, when understanding the spatial patterns of FP at the regional level, further research is needed. In this case, the IVH would be adapted to the latest trend towards capturing regional FP [66–68]. However, it should be highlighted that these new methodologies still fail to assess the remaining FP vulnerability after carrying out an energy-efficiency intervention and to provide an economic analysis of FP vulnerability.

4. Conclusions

This work demonstrates how the IVH can support both current policy delivery and implementation of alternative measures to addressing FP in England, by identifying households in greatest need, deploying public money prudently, and distributing FP resources effectively. The IVH, which was developed in Spain, has been adapted to the British context and applied to a particular case study in Salford, showing how vulnerable homes at risk of FP could be identified. The case study used in this work, selected via the IMD, is comprised of 102 households and represents a small geographical area with high vulnerability to FP. Furthermore, the dwelling type is pre-1919 terraced housing, representing 25.2% of the housing stock in England, and the three types of households defined represent the standard households with the highest rates of FP in England, providing local (city of Salford) and national (England) diversity of income levels, resource availability and socioeconomic characteristics.

The main conclusion from the case study analysis is the importance of household size and type in relation to vulnerability to FP. The proposed energy-efficiency intervention (the most common combination of energy-efficiency measures used in England) shows a reduction in FP vulnerability and highlights that the larger the household, the more difficult is to reduce the level of FP vulnerability. Furthermore, this shows that although dwellings would have been improved considerably after an energy-efficiency intervention, due to a lack of monetary resources, those low-income households would still have difficulties in paying their energy bills, and could therefore potentially remain in a situation of FP vulnerability.

Additionally, the assessment of thermal comfort in the dwelling made by the IVH evidences a potential for understanding the seasonality of vulnerability, as well as for determining optimal energy-efficiency measures. In addition, the relationship between FP and high energy consumption for cooling during warmer periods could be assessed, leading to a richer multi-dimensional analysis of FP. This is an important consideration when taking into account future situations of FP vulnerability due to climate change, and the implication of an unusual increase in the energy demand in England due to higher temperatures during summer. Furthermore, unlike current FP indicators used in England to assess FP, the economic analysis provided by the IVH allows for an estimation of savings to the NHS and therefore aids understanding of the economic and societal impact of policy decisions.

Regarding a recent call of the EU Parliament [69] in which it requested an evaluation of whether enough protection has been provided to citizens by current measures and indicators, the comparative analysis with the 10% and LIHC indicators hints at limitations of current FP indicators in terms of their ability to assess a FP situation fully and to provide a nuanced way of determining the level of vulnerability to FP in England. This has the potential for the HFP and “heating or eating” effect to remain undetected, evidencing the limitation of current tools to ensure that vulnerable consumers have access to basic energy services and that FP is reduced, suggesting that there is scope for refinement of the official indicators.

In view of relevant recommendations for policymakers to develop effective FP measures, this work shows that household size and income levels are key common factors in FP vulnerability; energy-efficiency interventions partially reduce households FP vulnerability; and effective FP measures must be defined according to housing, socioeconomic, environmental and climatological factors in each country. In conclusion, the IVH is therefore a comprehensive tool to assess FP vulnerability at a local scale in England.

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