Accepted for publication in Energy Efficiency

Energy consumption of buildings and urban energy poverty assessment: case study of a Madrid neighbourhood.

Jorge Gallego Sánchez-Torija[a,] *, María Antonia Fernández Nieto[b].

[a]* Department of Construction and Technology in Architecture, Superior Technical School of Architecture of Madrid, Polytechnic University of Madrid, Avda. Juan de Herrera 4, 28040, Madrid, Spain. (Corresponding author) jorge.gallego@upm.es Orcid: 0000-0002-3240-1883

[b] Architecture, Higher Polytechnic School, Universidad Francisco de Vitoria, Carretera Pozuelo a Majadahonda, Km 1.800, 28223 Madrid (Spain). a.fernandez.prof@ufv.es Orcid: 0000-0001-6569-5753

Abstract

The assessment of the energy consumption of buildings is essential in analysing energy poverty. Current indicators in Spain are based on real consumption. The aim is to advance with the assessment of theoretical energy consumption in order to understand the economic expense behind keeping a home at an adequate temperature, regardless of actual use of energy facilities, which might be low as a result of lack of resources or excessive due to lack of control. A simplified method is proposed for this, which allows for an agile assessment on an urban scale and which is applied to a vulnerable Madrid neighbourhood, Pan Bendito, in Spain. The household in Pan Bendito with electric heating find themselves in energy poverty due to the high economic cost of the aforementioned heating system. Households with gas heating, whose economic cost is lower, do not find themselves in energy poverty. Establishing a reduced price for adjusted consumption and a high price for excessive consumption is advisable.

Keywords

Energy poverty, Energy consumption in buildings, Vulnerable neighbourhoods, Indicators, Energy analysis on an urban scale

1. Introduction

Four southern European countries (Malta, Portugal, Cyprus and Spain) have significantly higher excess winter mortality than other European countries (Fowler, 2015). Until 2018 energy poverty had not been exhaustively examined in these countries (Kyprianou, 2019), despite the relationship between the two phenomena (Healy, 2003).

On April 5, 2019, the Government of Spain approved the National Strategy against Energy Poverty 2019–2024 (Ministerio para la Transisción Ecológica, 2019), hereinafter known as 'NSAEP'. This document establishes the national definition of energy poverty for the first time:

'Energy poverty is the situation in which a household cannot meet the basic needs of energy supplies, as a result of an insufficient level of income and which, where relevant, can be aggravated by an energy-inefficient home.'

This definition includes the three main factors to which Luxán attributes energy poverty in 2017: the high cost of energy bills, low household income and the poor energy efficiency of the homes (De Luxán García de Diego, 2017).

However, the definition of energy poverty is undergoing a process of revision at the international level depending on the different approaches applied.

In the UK a first definition from Bradshaw emerged in 1983 as the incapacity for adequate heat in the home (Bradshaw, 1983) and the first quantifiable definition of Boardman in 1991 as a household's inability to attain adequate energy services for less than 10% of its income (Boardman, 1991).

Later Moore defines energy poverty in 2012 as the situation of households whose equivalised household incomes, using OECD modified and companion scales, after housing and total fuel costs are deducted are under the minimum income standard (Moore, 2012). In 2017, Bouzarovski, with a broader vision, defines energy poverty as the inability to attain a socially and materially necessitated level of domestic energy services (Bouzarovski, 2017).

NSAEP defines a series of indicators to comply with article 40 of the draft of the internal market in electricity directive (European commission, 2017) that obliges member states to measure energy poverty. These indicators are intended to quantify the number of people in energy poverty.

The indicators established in the NSAEP are based on those proposed by the *Asociación de Ciencias Ambientales* (the Association of Environmental Sciences) in its 2018 report (Tirado Herrero, S., et al., Pobreza Energética en España. Hacia un sistema de indicadores y una estrategia de actuación estatal, 2018), which, in turn, are included in the EU Energy Poverty Observatory (EPOV):

1. Disproportionate expenditure (2M): the proportion of households whose share of income spent on energy is more than twice the national median share.

2. Hidden energy poverty (M/2): percentage of households whose absolute energy expenditure is less than half of the national median.

3. Inability to keep home adequately warm (KEEP WARM): percentage of the population unable to keep their home adequately warm.

4. Arrears on utility bills (ARREAS): the percentage of population having arrears on utility bills.

The four indicators are not exclusive; they are independent of each other. They offer four different results for households in an energy poverty situation. They do not offer accumulated results that report the number of indicators that each household meets.

According to the indicator used, between 3.5 and 8.1 million people are in a situation of energy poverty in Spain (Ministerio para la Transisción Ecológica, 2019). Despite having a milder climate than other northern countries in Europe, energy poverty numbers in Spain have increased since the 2008 economic crisis (Tirado Herrero, S., et al., 2016). Other causes of energy poverty in Spain are the low thermal quality of the envelope of most parts of the residential park (Lelkes, O., & Zólyomi, E., 2015) and the high number of inadequate heating installations (Oteiza, 2018).

The binary logic of the threshold by which it is determined whether a household is in energy poverty or not, depending on whether it does or does not exceed the indicator used, is chosen to measure energy poverty. Its application is simpler than other indicators that continuously measure the phenomenon and allow for finding out the intensity at which it is affected (Hills, 2012).

It is worth assessing this first effort made by the Spanish administration to quantify the scope of energy poverty in a simple, accessible and replicable way that allows for a comparison with other surrounding countries to be established. In turn, it should be taken into consideration that more precise tools should be developed in order to make energy poverty mitigation measures more effective.

The overall objective of this paper is to offer a methodology for calculating an urban energy poverty indicator on the basis of available secondary data such as housing type parameters as well as basic income, energy prices and consumption. To assess energy poverty, more disaggregated data than at the regional level would offer a more accurate diagnosis. Within the urban scale, the census section is the most disaggregated area with available data. Without more disaggregated scales studies mainly at the national, current policy efforts risk failing to actually alleviate energy poverty due to misrecognition of the problem and imprecise targeting (Sareen, 2020).

2. Background

Without pretending to be exhaustive and given that the in-depth analysis of this issue could be developed in an independent paper, the current discussion on the strengths and weaknesses of the indicators used in Spain is presented in a summarized way. Of all the indicators that have been used in the United Kingdom, where the government has been working against energy poverty for more than two decades, three have also been chosen: the first that emerged, the most important and the most recent.

1. Ten percent actual spend (10%): Households whose fuel expenditure on all energy services exceeded 10% of their income (Boardman, 1991).

2. Low income and high cost (LIHC): Households who have required fuel costs that are above the median level; and were they to spend that amount they would be left with a residual income below the official poverty line (Hills, 2012) (Department of Energy and Climate Change (DECC) & Building Research Establishment (BRE)., 2019).

3. Low Income Low Energy Efficiency (LILEE): Households with a Fuel Poverty Energy Efficiency Rating (FPEER) of Band D, E, F, or G and after housing and energy costs are deducted, have their disposable income defined as below the poverty line (National Energy Action (NEA) and Energy Action Scotland (EAS) National Energy Action, 2019).

Finally, the indicator in which this paper goes into depth is also shown. To try to overcome the detected weaknesses, Romero proposes working with the Theoretical Expenditure Data (TED) necessary for maintaining adequate comfort, instead of opting for the actual energy expenditure data (Romero J. C., 2018).

Table 1. shows the main strengths and weaknesses of the aforementioned indicators.

Table 1. Strengths and weaknesses of the different indicators.

Ambit	Indicator	Strengths	Weaknesses
Spain	2M	Simple to calculate. Accessible: calculated using data collected from the Family Budget Survey (FBS) (Instituto Nacional de Estadística, 2017) and Survey into Income and Living Conditions (SILC) (Instituto Nacional de Estadística, 2017). Replicable. Allows comparison with neighbouring countries (Thomson, 2018).	Includes unnecessary consumption of resources (Moore, 2012).
	M/2		Benefits households in favourable climate zones whose demand for heating is 20 times lower than in unfavourable climate zones (Grupo de Termotecnia de la Escuela Superior de Ingenieros Industriales de la Universidad de Sevilla, 2009).
	KEEP WARM ARREAS		Unreliable, it does not reflect reality because it is a subjective approach (Romero J. C., 2014).
United Kingdom	10%	Simple to calculate (Boardman, 1991).	Arbitrary selection of the threshold at 10% (Rademaekers, 2016). Excludes those who suffer from energy deprivation (Rademaekers, 2016). Includes unnecessary consumption of resources (Moore, 2012).
	LIHC	Excludes unnecessary consumption of resources (Hills, 2012).	Ineffective as it is difficult to obtain (National Energy Action (NEA) and Energy Action Scotland (EAS) National Energy Action, 2019).
	LILEE	Simple to calculate (Grupo de Termotecnia de la Escuela Superior de Ingenieros Industriales de la Universidad de Sevilla, 2009).	Includes unnecessary consumption of resources (Moore, 2012). Excludes low-income families whose household is efficient.
Paper	TED	Allows comparison because it eliminates differences in energy use and level of comfort achieved (Romero J. C., 2018).	It is not accessible since it does not use available data. Oversized results (Hills, 2012) (Parés, 2015).

3. Scope of the study

The study was carried out in the Pan Bendito neighbourhood, located in the Carabanchel district of Madrid, as can be seen in Figure 1.

Figure 1. Carabanchel district of Madrid (Tyk, 2016) and the Pan Bendito neighbourhood within Carabanchel (Ayuntamiento de Madrid, 2017).

This case study is chosen for the following reasons: its negative social perception, its disadvantaged socio-economic situation and its consideration as a vulnerable neighbourhood.

It is considered one of the worst areas in Madrid. This stigmatisation can be felt in the article published by the El País newspaper, 'The seven deadly sins of Pan Bendito' (Martín, 2010). The caption reflects various socio-economic problems in the neighbourhood: "A week in one of Madrid's most disadvantaged neighbourhoods, where the highest unemployment rates, drugs, neighbourhood conflicts and the abandonment of its streets coexist."

The perception that Spanish society has of Pan Bendito is also reflected by Villalón in his book published by a university editorial (Villalón, 2019) in which he mentions Pan Bendito as one of the 65 Spanish neighbourhoods considered as a place of marginalization, disorder and crime.

Below, Table 2 shows the main data on the socio-economic situation of Pan Bendito in comparison with the Carabanchel district to which it belongs and the city of Madrid.

Table 2. Main data on the socio-economic situation of Pan Bendito.

	Year	Madrid	Cara-banchel	Pan Bendito	Source
Average age of population (years)	2017	43.5	42.9	40.9	(Instituto Nacional de Estadística, 2017)
Population under 18 (%)	2017	16.1	16.7	20.6	
Population aged 65 and over (%)	2017	20.3	19.5	17.3	
Foreign population (%)	2017	13.1	17.8	19.1	(Ayuntamiento de Madrid, 2017)
Average household size (persons)	2017	2.49	2.58	2.93	(Instituto Nacional de Estadística, 2017)
Single-person households (%)	2017	30.8	28.9	24.8	
Average income per household (€)	2017	40,195	28,721	21,077	

Absolute rate of registered unemployment (%)	2017	9.3	11.6	12.0	(Ayuntamiento de Madrid, 2017)
Population with university studies (%)	2017	35.2	19.7	6.5	
Owned homes (%)	2017	76.7	73.0	82.3	(Instituto Nacional de Estadística, 2017)
Rented housing (%)	2017	16.9	24.3	4.9	
Price of the second hand property (€/m^2)	2017	3,285	1,874	1,644	(Ayuntamiento de Madrid, 2017)

As can be seen, the Carabanchel district has a 0.6 year younger population, a 36% higher foreign population, a 29% lower income, a 25% higher unemployment rate, 44% fewer people with university studies and a housing price per m^2 that is 43% lower than the city of Madrid.

The socio-economic situation of the Pan Bendito neighbourhood is even worse. It has a 2.6 year younger population, a 46% higher foreign population, a 48% lower income, a 29% higher unemployment rate, 82% less population with university studies and a housing price per m^2 50% lower than the city of Madrid.

It draws attention to the very low percentage of rental housing. As this is public housing, the official data is underestimated. They do not include the actual number of rented dwellings due to the fact that the regulations of the housing protection regime do not allow them to be rented.

The Atlas of Urban Vulnerability in Spain includes the 2001 and 2011 editions. It is part of the Vulnerability Observatory developed by the Ministry of Development (Ministerio de transportes, movilidad y agenda urbana, 2011). It conceives urban vulnerability as that process of unrest in cities produced by the combination of multiple dimensions of disadvantage, in which any hope of upward social mobility, of overcoming their social condition of exclusion or close to it, is seen as extremely difficult to achieve (Hernández Aja A. V., 2012).

Vulnerability is analysed on the basis of 24 indicators and 33 complementary statistical variables, grouped into four dimensions of vulnerability: Socio-demographic, Socio-economic, Residential and Subjective.

Pan Bendito is one of the 91 vulnerable neighbourhoods in Madrid. It has a medium level of vulnerability. There are only two neighbourhoods with high levels of vulnerability and 25 neighbourhoods with a medium level. The 2001 record indicates that it is one of the worst neighbourhoods in Madrid.

The demarcation of the neighbourhood is a source of argument and disagreement because the territory is now of great importance to the constitution of identity and the significance of belonging (Asociación la Rueca, 2018).

Although this district has not been officially defined by the administration, the name 'Pan Bendito' is referred to in various documents. It is the name of the Line 11 metro station located in the area. The perimeters of the Pan Bendito neighbourhood vary depending on the source consulted. For this article, the criterion used by Hernández Aja for the demarcation of vulnerable neighbourhoods has been followed: 'They are urban delimitations of perimeters that correspond to a physical and morphological logic of certain homogeneity and continuity' (Hernández Aja A. R., 2018).

Census sections belonging to the Pan Bendito neighbourhood according to the different sources consulted and those finally included in this paper can be seen in figure 2 and table 3.

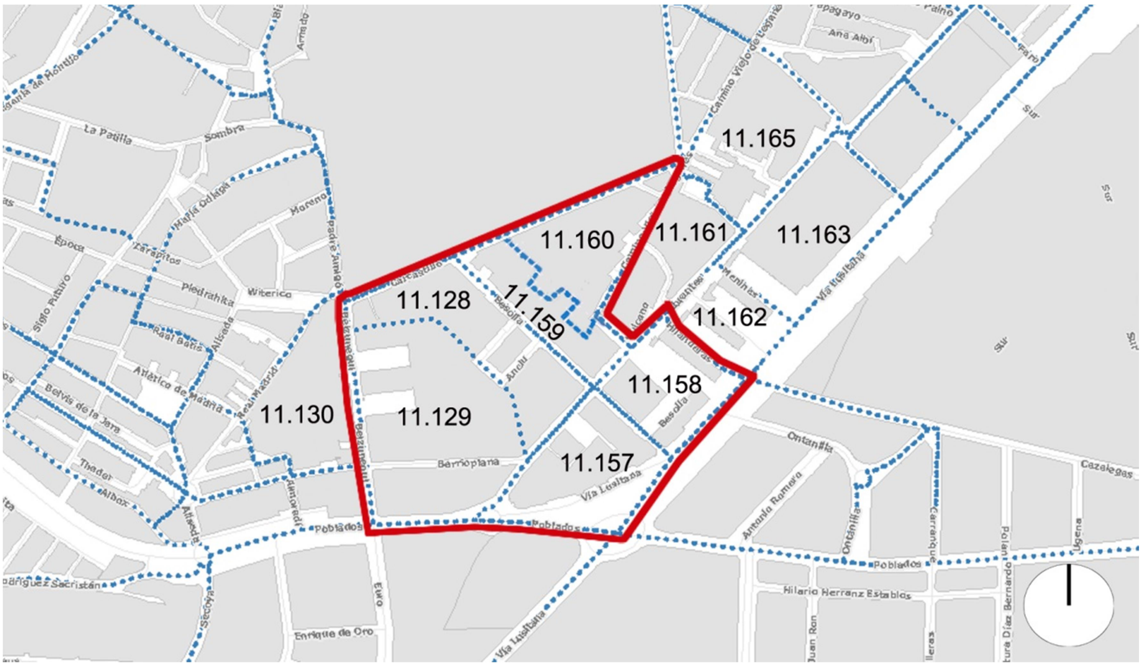

Figure 2. Census sections belonging to the Pan Bendito neighbourhood (Instituto de Estadística de la Comunidad de Madrid, 2019).[38]

Table 3. Census sections belonging to the Pan Bendito neighbourhood according to the different sources consulted.

Source	**11.128**	**11.129**	**11.130**	**11.157**	**11.158**	**11.159**	**11.160**	**11.161**	**11.162**	**11.163**	**11.165**
Integrated Planning Area API 11.06 Pan Bendito, General Urban Development Plan for Madrid (Ayuntamiento de Madrid, 2014)	X	X		X	X	X	X				
Atlas of urban vulnerability (Hernández Aja A. R., 2018)	X	X	X	X	X	X	X				
Community diagnosis by the La Rueca Association (Asociación la Rueca, 2018)	X	X	X	X	X	X	X				
Neighbourhood Plan for Pan Bendito 2009-2012 by the Madrid City Council (Ayuntamiento de Madrid, 2009)	X	X		X	X	X	X	X	X	X	X
Comprehensive Neighbourhood Plan 2019 by the Madrid City Council (Ayuntamiento de Madrid, 2019)	X	X	X	X	X	X	X	X	X	X	X
Demarcation of parishes by the Statistical Institute of the Community of Madrid (Instituto de Estadística de la Comunidad de Madrid, 2019)	X	X		X	X	X	X				
Demarcation adopted in the paper	X	X		X	X	X	X				

The demarcation of the Pan Bendito neighbourhood that has been established as a study scope includes census sections 11.128, 11.129, 11.157, 11.158, 11.159 and 11.160.

Census section 11.130 is excluded from the study scope because it belongs to the Torres Garrido neighbourhood and the residents feel they belong to the San Francisco neighbourhood. In fact there is a Line 11 metro stop with the same name near the census section.

Census sections 11.161, 11.162, 11.163 and 11.165 are excluded from the study scope because they belong to the Velázquez neighbourhood. It is a different physical reality with a differentiated denomination.

Figure 3 shows different images of the Pan Bendito neighbourhood.

Figure 3. Aerial photo of Pan Bendito when the metro was built in 1998 (Comunidad de Madrid, 1998) and inner street of the neighbourhood (Martín, 2010).

4. Methodology

The proposed methodology consists of nine steps that are described in table 4.

Table 4. Proposed methodology

Analysis	Data	Source	Formula	Result
1. Economic	Average household income	Atlas of household income distribution (Instituto Nacional de Estadística, 2017)	-	-
2. Urban	Number of household and year of construction	Publications of the time (Moya González, 1983) (Ministerio de Obras públicas y urbanismo, 1984)	-	-
3. Morphological	Classification of the type of housing according to height and shape.	Official mapping (Instituto de Estadística de la Comunidad de Madrid, 2019) Spanish National Research Council (Oteiza, 2018) (Domínguez Amarillo, 2016)	-	-
4. Constructive	Classification of the thermal envelope	Kurtz methodology (Kurtz, 2015)	-	-
5. Demand for heating and cooling	Block orientation and sunlight Percentage of windows Geometric aspects: Compactness and slenderness Household surface area	General Directorate of Cadastre (Dirección General del Catastro, 2019) On-site data collection	Compactness and slenderness (Serra Florensa, 1995) Heating and cooling demand: Monzón multiple linear regression model (Monzón, 2017)	Heating and cooling demand per household (kWh)
6. Demand for domestic hot water	People per household	Population census (Instituto Nacional de Estadística, 2011)	Atecyr (Atecyr, 2010)	Domestic hot water (DHW) demand per household (kWh)

7. Energy consumption	Performance of heating, cooling and DHW systems using the various energy sources available	National Centre for Renewable Energies (Centro Nacional de Energías Renovables, 2016) Gallego (Gallego Sánchez-Torija, 2018) Institute for Energy Diversification and Saving (García Montes, 2011)	Consumption (kWh) = demand (kWh) / performance (%)	Total energy consumption per household (kWh)
	Energy consumption of cooking, lighting and appliances	Eurostat (Eurostat, 2017)	-	
8. Economic cost of energy consumption	Price of available energy sources	Eurostat (Eurostat, 2017) (Eurostat, 2017)	Tariff structure of available energy sources	Economic cost of energy consumption (€)
9. Energy poverty	National median energy expenditure in relation to income	Environmental Science Association (Tirado Herrero, S., et al., 2018) using data from the FBS (Instituto Nacional de Estadística, 2017)	Economic cost of energy consumption (result point 8) in relation to household income (result point 1) more than twice the national median	Energy poverty (yes/no)

The methodology described allows the evolution of energy poverty to be monitored over time. To do this it would be necessary to update the data that vary over time. The characteristics can be seen in table 5.

Table 5. Characteristics of data that vary over time.

Data	**Source**	**Last year available (Year used)**	**Update frequency**
Average household income	Atlas of household income distribution (Instituto Nacional de Estadística, 2017)	2017 (2017)	Every year
People per household	Population census (Instituto Nacional de Estadística, 2011)	2011 (2011)	Every 10 years
Energy consumption of cooking, lighting and appliances	Eurostat (Eurostat, 2017)	2017 (2017)	Every year
Price of available energy sources	Eurostat (Eurostat, 2017) (Eurostat, 2017)	2019 (2017)	Every year
National average energy expenditure in relation to income	Family budget survey (Instituto Nacional de Estadística, 2017)	2018 (2017)	Every year

People per household is a data that presents a small variation, so it can be considered stable throughout the decade in which updated data are not available. The use of the rest of the data that present variations in time to the year 2017, the last year available for the four, has been unified.

By accessing future data updates, the proposed methodology makes it possible to monitor the evolution of energy poverty over time.

As for the formulas used, these are common formulas in this type of calculation that are easy to use. The only complex calculation is that for the demand of heating and cooling for which the Monzón multiple linear regression model is adopted (Monzón, 2017). Monzón has developed a model that allows the values required to be obtained in a simplified way. This model has been proposed in a study of social housing in Zaragoza. As Madrid and Zaragoza are in the same climatic zone, D3, the study of Zaragoza can be applied directly to Madrid without the need for adjustments. For other cities in other climate zones, it would be necessary to develop the Monzón model incorporating the climate variable.

In order to verify the usability of the methodology, a field study has been conducted by interviewing a social worker who has been working with the vulnerable population of the neighbourhood for more than 20 years. Her contributions are included in the text. With her vision the results obtained in a theoretical way can be better contrasted with the social reality of the neighbourhood, especially that of the socially disadvantaged people, which would perhaps be more difficult to obtain through the carrying out of surveys.

5. Results

5.1. Economic analysis

The average household income in the year 2017 is shown in table 6. The Pan Bendito neighbourhood is in the lowest household income bracket of Madrid.

Table 6. Average household income in 2017 (Instituto Nacional de Estadística, 2017)

Area	Average household income (€)
Madrid	38,535
Carabanchel	27,936
11.128	20,607
11.129	18,590
11.157	24,509
11.158	19,569
11.159	21,831
11.160	22,112

The income of the most vulnerable households in the neighbourhood served by the social worker is considerably lower than that collected by the official average income data.

5.2. Urban analysis

In 1957, the Vista Alegre Minimal Absorption Settlement (MAS) was built by Mariano Rodríguez Avial. It consists of 781 homes, made up of semi-detached family homes and 4-storey blocks of flats.

In 1963, the Pan Bendito Neighbourhood Absorption Unit (NAU) was built by Luis Vázquez de Castro, María Juana Ontañón and Manuel López Mateos. It consists of 656 semi-detached family homes.

These two developments erected between 1957 and 1963 were intended for the temporary relocation of immigrants arriving in the capital, mainly from Andalusia and Extremadura. They are included in what Rodríguez Villasante calls 'official slums' (Rodríguez Villasante, 1989).

In 1970, the first phase of the 'Complementary screen blocks in the Pan Bendito sector' project on Vía Lusitana Street was completed, designed by María Juana Ontañón, López Mateos and Luis Vázquez de Castro. It comprised 332 homes in 4- and 8-storey blocks of flats and 12-storey tower blocks.

The second phase of the previous project was completed in Camino Viejo de Leganés Street between the years 1973 and 1975. It consists of 276 homes in 4- and 8-storey blocks of flats and 12-storey tower blocks, in addition to a school and a nursery.

These four public social housing developments carried out by the Trade Union Welfare Fund for the Home Complete, initially, the scope of the present study: the Pan Bendito neighbourhood, as reflected in Figure 4.

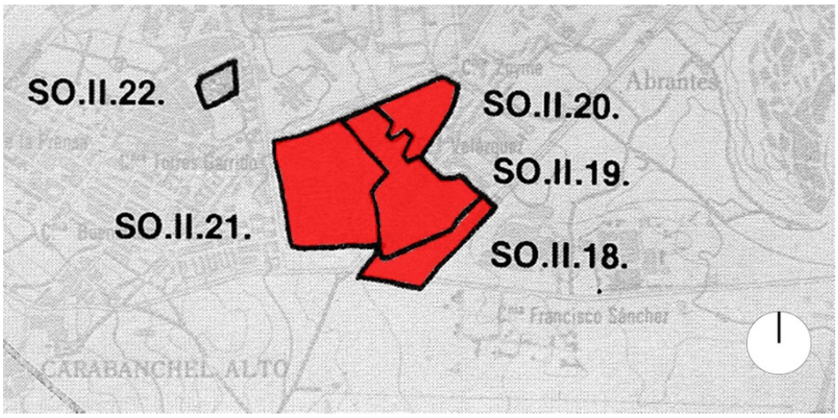

Figure 4. Developments up to 1972 in the Pan Bendito neighbourhood (Moya González, 1983): SO.II.18 Vía Lusitana, SO.II.19 Pan Bendito NAU, SO.II.20 Camino Viejo de Leganés and SO.II.21 Vista Alegre MAS.

In 1979, the Madrid Housing Institute (MHI) began the Neighbourhood Remodelling Program. It provides for the integral remodelling in situ, consisting of the gradual demolition of the Vista Alegre MAS and the Pan Bendito NAU, both provisional, to build new homes on the ground being freed up. Between 1982 and 1987, 1,404 homes were built (Ministerio de Obras públicas y urbanismo, 1984) in 6 and 8-storey blocks of flats 10 and 14-storey tower blocks.

The urban structure is made up of independent blocks and towers or of groups of two to five aligned buildings or with small displacements when juxtaposed. Large, pedestrian-landscaped or sports spaces remain between the buildings.

Currently, the Pan Bendito neighbourhood is made up of 332 + 276 + 1,404 = 2,012 homes. Its surface is 24.3 ha and its density is 82.8 dwellings/hectare, which is close to the design criteria for sustainable residential areas suggested by López de Lucio, who recommends 75–80 dwellings/hectare (López de Lucio, 2007), for building the city on the periphery.

It is a long way from the high density areas of Madrid's historic centre, such as the Embajadores neighbourhood, which has 237 dwellings/hectare, or the mid-19th-century extension, such as the Goya neighbourhood, which has 220 dwellings/hectare. It is also a long way from the low density neighbourhoods built in the 1960s, such Colonia Manzanares, with 30 dwellings/hectare (Zapatero Santos, 2017).

As regards the ownership regime, the households are registered in the name of MHI, who in turn has signed a private purchase contract with the owners, when the households are not rented. Over time, some households have been registered in the property register in the name of their owners, while other properties continue to be registered as property with the IVIMA. There's no official data about this.

5.3. Morphological analysis

As for height restrictions, the maximum height, as established by Oteiza (Oteiza, 2018), of 28 metres or 9 floors is used, as it is the maximum height established by the Technical Building Code for adopting special fire protection measures for high-rise buildings. The buildings, according to their height, are classified in blocks when they have a maximum of 9 floors and in towers from 10 floors upwards.

As for the general shape of the building, Dominguez (Domínguez Amarillo, 2016) and Oteiza's (Oteiza, 2018) classification criteria is used. In the scope of action, five types of buildings are identified: linear block, L-shaped block, H-shaped block, linear tower and H-shaped tower.

The residential buildings belonging to the scope of action classified according to the promotion to which they belong and the number of plants are detailed in figure 5.

Figure 5. Classification of all residential buildings belonging to the field of action. Source: author's own.

The absence of single-family homes is notable. The most common type of building (63%) is a vertical building with eight floors, while there are less than 10% of the rest of the building types in the sample.

Only two buildings are separate (3%). The rest are arranged in groups: some are joined at the corner (10%), others are in pairs (33%), trios (16%), groups of four (22%) and other more complex groupings (16). The buildings are joined both without displacement between them as well as with displacements that allow for the opening of gaps in part of the juxtaposed façades. The existence of dividing walls implies a decrease in energy demand.

5.4. Constructive analysis

The three currently existing developments were built in the 1970s. Although the last of the three was completed at a later date, its project was started prior to the effective date of the Basic Standard of Thermal Conditions in Building NBE-CT-79. The constructive solutions of the three developments (the first two belong to the same project that runs in two phases and in two separate zones) have the same thermal characteristics. The different blocks, even within the same development, vary in brick colour and in their morphology and the composition of openings.

The constructive solution of the façade enclosures used in all the buildings studied is: ½ foot of brick, air chamber, single hollow brick partition and plaster. Its thermal transmittance U is 1.65 W/m^2K. It corresponds to type F.9 (Kurtz, 2015).

The constructive solution of the ground of the building is an insulating suspension on the ground floor. This corresponds to type F.S.1, classified within group 2 (Kurtz, 2015).

The number of homes located on the ground floor is 258, which represents 12.8% of the total number.

The roof is made of ceramic tile, compression layer, scratch board, dovecot partition, unidirectional slab and plaster. The thermal transmittance U is 1.27 W/m^2K. This corresponds to type C.4 (Kurtz, 2015).

The openings have aluminium carpentry without a thermal break with a 5 mm single pane of glass (single glazed). The thermal transmittance U is 5.7 W/m^2K.

The openings have their corresponding sun protection consisting of an external roller shutter.

5.5. Analysis of the demand for heating and cooling

The annual heating and cooling energy demand are calculated according to the following expressions using the Monzón multiple linear regression model (Monzón, 2017):

Heating energy demand = 470.29 – 322.73 F1 – 364.18 F2 – 4.81 Fl1 + 30.83 Fl2 – 61.80 R – 0.19 %wSSF –2.16 %wISF + 0.30 %SSF + 0.20 %ISF + 6.39 %DW − 11.75 C − 2.19 S

Cooling energy demand = 47.34 – 27.09 F1 – 30.34 F2 –4.46 Fl1 – 0.35 Fl2 – 3.35 Roof + 0.02 %wSSF – 0.11 %wISF – 0.03 %SSF – 0.05 % ISF + 0.13 %DW + 3.45 C − 0.78 S

The variables used by the model to obtain the desired results are:

- Variables that depend on the composition of the envelope:
    - F1: Facade 1
    - F2: Facade 2
    - FL1: Floor 1
    - FL2: Floor 2
    - R: Roof
- Variables that depend on the percentage of openings:
    - wSSF: Window spaces sufficiently sunlit facade
    - wISF: Window spaces insufficiently sunlit façade
- Variables that depend on the orientation of the building:
    - SSF: sufficiently sunlit façade
    - ISF: insufficiently sunlit facade
- Variables that take the geometric aspects into account:
    - DW: Division wall
    - C: Compactness
    - S: Slenderness

The 73 existing residential buildings in the Pan Bendito neighbourhood have been individually analysed. To facilitate the reading of the results, the average values of the different census sections are shown in Table 7.

Table 7. Matrix of the variables for the multiple linear regression model of Monzón (Monzón, 2017).

Census section	**Facade 1**	**Facade 2**	**Floor 1**	**Floor 2**	**Roof**	**% window spaces sufficiently sunlit facade**	**% window spaces insufficiently sunlit facade**	**% sufficiently sunlit facade**	**% insufficiently sunlit facade**	**% dividing wall**	**Compactness**	**Slenderness**	**Heating energy demand (kWh/m^2)**	**Cooling energy demand (kWh/m^2)**
11.128	0	1	0	1	0	21	21	46	46	8	0.78	0.90	105	14
11.129	0	1	0	1	0	23	23	25	25	14	0.80	0.91	92	16
11.157	0	1	0	1	0	21	21	43	45	12	0.77	0.94	106	15
11.158	0	1	0	1	0	23	24	43	43	14	0.78	0.92	93	14
11.159	0	1	0	1	0	23	23	44	44	13	0.78	0.93	101	15
11.160	0	1	0	1	0	19	19	47	46	7	0.72	0.87	110	14

The heating demand in kWh/m^2 in the census section 11.129 is 13% lower than the worst census section. Two factors are responsible for this. The first is compactness, which is a result of the fact that the buildings have eight floors, while other census sections also have four-floor buildings. Secondly, it is built on a north/south axis, while the rest of the census sections are built on a south-east/north-east axis.

Next, the values obtained for heating and cooling in kWh/m^2 were multiplied by the average household surface area in each census section (Dirección General del Catastro, 2019) to find the respective annual demand for heating and cooling in kWh, as shown in Table 8.

Table 8. Annual demand for heating and cooling in the houses located in the different census sections.

Census section	**Heating energy demand (kWh/m^2)**	**Cooling energy demand (kWh/m^2)**	**Household surface area (m^2)[47]**	**Annual heating energy demand (kWh)**	**Annual cooling energy demand (kWh)**
11.128	105	14	91.4	9,597	1,280
11.129	92	16	91.7	8,436	1,467
11.157	106	15	90.3	9,572	1,355
11.158	93	14	79.4	7,384	1,112
11.159	101	15	96.7	9,767	1,451
11.160	110	14	84.6	9,306	1,184

It can be seen that the heating demand in census section 11.158 is 25% lower than the worst census section. This large difference occurs because of the difference in the surface of the dwellings in the different census sections.

5.6. Analysis of the demand for domestic hot water

The annual energy demand for the preparation of domestic hot water is calculated according to the following formula (Atecyr, 2010):

D_{DHW} (kWh) = C_{DHW} (l/p·d) · P_h (p) · 365 d · ($T_{DHW} - T_{CW}$) (°C) · 0.00116 kWh/l·°C

Where:

C_{DHW} = Consumption of DHW. According to current Spanish regulations, this is 28 litres 60ºC per person in the household (Ministerio de Fomento, 2013).

P_h = People per household. According to census data, the average is 2.6 people per home in year 2017 in Pan Bendito (Instituto Nacional de Estadística, 2011).

T_{DHW} = Supply temperature of DHW, 60ºC.

T_{CW} = Temperature of cold water, 13ºC in Madrid (Ministerio de Fomento, 2013).

It follows that the annual demand for energy for heating domestic hot water is:

D_{DHW} = 28 · 2.6 · 365 · (60-13) · 0.00116 = 1,449 kWh

5.7. Analysis of energy consumption

The households located in the Pan Bendito neighbourhood use either electricity as the only energy supply, or natural gas and electricity.

Households that use electricity for heating and supplying DHW obtain an output of 100% on heating by the Joule effect (Centro Nacional de Energías Renovables, 2016) and 60% in DHW by storing water in an electric boiler (Gallego Sánchez-Torija, 2018).

Households that use natural gas for heating and DHW obtain an output of 75% for both services (IDAE, 2011).

Output for refrigeration in the households is 356% (García Montes, 2011).

Energy consumption by cooking, lighting and appliances has been taken from the Eurostat study Energy consumption in households (Eurostat, 2017).

Table 9 shows the results of energy consumption in the households of the different census sections of the Pan Bendito neighbourhood.

Table 9. Final energy consumption in households in 2017 by type of end-use and total in the different census sections of the Pan Bendito neighbourhood expressed in kWh according to the type of supply.

<table>
<tr><th rowspan="2">Census section</th><th colspan="8">Final energy consumption by type of end-use (kWh)</th><th colspan="3" rowspan="2">Total Final energy consumption in 2017 (kWh)</th></tr>
<tr><th colspan="2">Heating</th><th>Coo-ling</th><th colspan="2">Domestic hot water (2017)</th><th colspan="2">Cooking (2017)</th><th>Lighting and applian-ces (2017)</th></tr>
<tr><th>Supply</th><th>El.</th><th>Gas</th><th>El.</th><th>El.</th><th>Gas</th><th>El.</th><th>Gas</th><th>El.</th><th>Only El.</th><th>Gas</th><th>El.</th></tr>
<tr><td>11.128</td><td>9,597</td><td>12,796</td><td>359</td><td rowspan="6">2,415</td><td rowspan="6">1,932</td><td colspan="2" rowspan="6">754</td><td rowspan="6">2,831</td><td>15,956</td><td>15,482</td><td>3,190</td></tr>
<tr><td>11.129</td><td>8,436</td><td>11,249</td><td>412</td><td>14,848</td><td>13,935</td><td>3,243</td></tr>
<tr><td>11.157</td><td>9,572</td><td>12,762</td><td>380</td><td>15,952</td><td>15,448</td><td>3,211</td></tr>
<tr><td>11.158</td><td>7,384</td><td>9,846</td><td>312</td><td>13,696</td><td>12,532</td><td>3,143</td></tr>
<tr><td>11.159</td><td>9,767</td><td>13,022</td><td>407</td><td>16,174</td><td>15,708</td><td>3,238</td></tr>
<tr><td>11.160</td><td>9,306</td><td>12,408</td><td>333</td><td>15,639</td><td>15,094</td><td>3,164</td></tr>
</table>

Figure 6 shows the distribution of energy consumption for homes that only have electricity and those that have electricity and natural gas as energy supply sources.

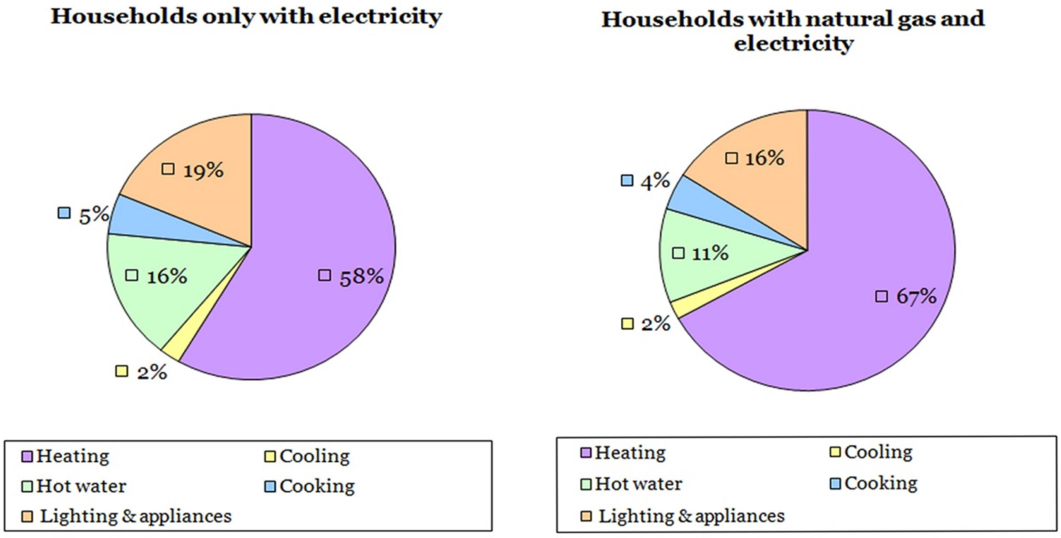

Figure 6. Distribution of electricity consumption in households that only have electricity and those that have electricity and natural gas as energy supply sources.

5.8. Analysis of the economic cost of energy consumption

In order to study the economic cost of electricity consumption, the bill is divided into three parts: the term on the contracted power, the term of the consumption and other items, such as the rent of the meter. As regards gas, there are only two sections: set term and variable term. Taxes are applied to each part of the concept separately in order to analyse the impact on the bill if any of the parameters were modified: contracted power, cost of the company for the power term and consumption term.

Households that only have electricity as the only energy supply have to contract electrical power of 4.4 kW. It could be higher, but this has been rejected in view of the neighbourhood's low income. However, the households that have electricity and gas natural as sources of energy supply only need to contract electrical power of 3.3 kW.

The different prices are obtained from the report for the year 2017 "Energy consumption in households" from Eurostat (Eurostat, 2017). Table 10 retains the results of the annual economic cost associated with the energy consumption of the households of the different census sections of the neighbourhood of Pan Bendito according to the type of supply.

Table 10. Cost of energy consumption in 2017 in the different census sections of the Pan Bendito neighbourhood in € according to type of supply.

Census section	Electricity power (kW)	Power term (€/kW)	Power term cost after tax (€)	Electricity energy consumption (kWh)	Electricity consumption energy term cost after tax (€)	Electricity consumption energy term cost after tax (€)	Cost of other items after tax (€)	Total electricity energy cost (€)	Natural gas fixed term cost of consumed energy term after tax (€)	Natural gas consumption (kWh)	Natural gas variable term (€/kWh)	Natural gas variable term cost after tax (€)	Total natural gas cost (€)	Total energy cost (€)
Households with electricity only														
11.128	4.4	3.429798	230	15,956	0.115412	2,342	20	2,592			-			2,592
11.129				14,848		2,180		2,430						2,430
11.157				15,952		2,342		2,592						2,592
11.158				13,696		2,010		2,260						2,260
11.159				16,174		2,374		2,624						2,624
11.160				15,639		2,296		2,546						2,546
Households with natural gas and electricity														
11.128	3.3	3.429798	173	3,190	0.115412	468	20	661	123	15,482	0.04473	882	1,005	1,666
11.129				3,243		476		669		13,935		794	917	1,586
11.157				3,211		471		664		15,448		880	1,003	1,667
11.158				3,143		461		654		12,532		714	837	1,491
11.159				3,238		475		668		15,708		895	1,018	1,686
11.160				3,164		464		657		15,094		860	983	1,640

5.9. Energy poverty analysis

The national average for energy costs in relation to income in 2017 was 4.8% (Tirado Herrero, S., 2018). Therefore the disproportionate expense indicator (2M) places the threshold of energy poverty in those households that spend more than double this percentage (9.6%) of their income on energy bills (Ministerio para la Transisción Ecológica, 2019).

Table 11 shows the census sections of the Pan Bendito neighbourhood with energy poor households according to the 2M indicator in relation to the type of supply available.

Table 11. Energy poverty households in 2017 in different census sections of the Pan Bendito neighbourhood according to the 2M indicator in relation to the type of supply available.

Census section	Total energy cost (€)	Household income energy poverty threshold (€)	Household income (€)	Energy poverty
Households with electricity only				
11.128	2,592	27,000	20,607	Yes
11.129	2,430	25,313	18,590	Yes
11.157	2,592	27,000	24,509	Yes
11.158	2,260	23,542	19,569	Yes

11.159	2,624	27,333	21,831	Yes
11.160	2,546	26,521	22,112	Yes
Households with natural gas and electricity				
11.128	1,666	17,354	20,607	No
11.129	1,586	16,521	18,590	No
11.157	1,667	17,365	24,509	No
11.158	1,491	15,531	19,569	No
11.159	1,686	17,563	21,831	No
11.160	1,640	17,083	22,112	No

6. Discussion of the results

Firstly, the evaluation of the proposed methodology is addressed.

The available data on average household income provided by the National Institute of Statistics is broken down by census sections, which provides an important level of disaggregation. However, in order to be able to more accurately assess the incidence of energy poverty in the different census sections, it would be desirable to have the average values per income quintile in addition to the average value.

Aplying Monzón's multiple lineal regression model (Monzón, 2017) for calculating the demand for heating and cooling, some limitations have been observed.

There is a lack of dividing walls in the sample. These are only present in three of the 26 buildings studied, and they represent a percentage of surface that remains below 6%. It is observed that the coefficient that is applied is positive when the existence of dividing walls should reduce the demand for heating and cooling. Ideally, the formula obtained would be calibrated with the incorporation of more cases with a significant percentage of dividing walls.

In addition, the Monzón model has been developed for climate zone D3, with which 12% of the Spanish cities that cover 29% of the population could be analyzed. To be able to apply the model in other cities it would be necessary to develop it by incorporating the climate variable.

Once this development is carried out, the proposed methodology will be applicable in all cities, both Spanish and European, given that the data used are available in these countries.

The greater or lesser homogeneity of the buildings in the area studied is not a problem for the reproducibility of the method. It is sufficient to classify each type of building according to the aforementioned criterion. Only the Monzón model excludes single family housing because its high revaluation does not enable it to be included in the vulnerability concept (Monzón, 2017).

The methodology allows the evolution of energy poverty to be monitored over time. There are data that do not vary. It is only necessary to obtain them when the analysis is carried out for the first time. Other data vary over time. They have been collated in table 5. Data from 2017 have been used and they are the last ones available. By accessing future updates of the referenced sources, it would be possible to obtain the update of energy poverty for successive years.

Table 12 details the results obtained from the total consumption of the dwellings of Pan Bendito which were compared with the average consumption values in Madrid outlined in Martín-Consuegra (Martín-Consuegra, 2019).

Table 12. Total consumption in households only with electricity and households with natural gas and electricity (kWh) in Pan Bendito and in Madrid in 2017.

Place	Households with electricity only	Households with natural gas and electricity
Pan Bendito	15,378	17,898
Madrid	14,436	17,873

It was found that energy consumption in Pan Bendito households is similar to the average for Madrid. Households in Pan Bendito that only have electricity consume 7% more than the average for Madrid, while those in Pan Bendito that have both gas and electricity consume the same. This is because the methodology used by Martín-Consuegra did not take into account the difference in performance in the supply of DHW between an instant-supply appliance that uses gas (combination boiler for heating and DHW) and a water-storage appliance that uses electricity (electric boiler). While it is true that heating consumption is higher, accounting for about 59% of the total, the consumption of DHW is the second most important with 16% of the total.

Households that have gas and electricity, despite paying 33% more in the fixed part of the bill for having a dual supply, save around 66% on their bills compared with households which only have electricity because the price of electric energy consumed is 243% more than gas consumed.

As a consequence of the current tariff structure, households that do not have gas heating installed and are forced to heat homes using electric radiators have seen their energy bills increase by 152%. Households with less economic power to invest in gas heating pay more to keep their homes warm. In the Pan Bendito neighbourhood, all the households that do not have gas heating installed are energy poor. Households that do have gas heating installed are not in energy poverty.

On the other hand, the impact of cooling appliances on energy poverty should also be noted. As shown in Figure 6, it represents 2% of energy consumption when the method of calculation considers that the demand for cooling is attended when necessary. The SPAHOUSEC study (IDAE, 2011)[62] for block housing in continental climates notes that this consumption is reduced by 1%. Among other factors, this is because this study quantifies real consumption, not the theoretical demand that would achieve a level of comfort. And this is precisely what is not done where there is no cooling appliance installed.

Additionally, it would be desirable to update the methods of calculation for cooling consumption in the context of climate change. Heat waves are becoming more frequent and more intense. The highest ever recorded temperature in Madrid occurred in June 2019 (Agencia Estatal de Meteorología AEMET, 2019). This increase in temperatures implies an increase in the energy necessary to maintain a level of comfort inside buildings.

Owing to the low economic impact of keeping households cool, the indicator used implies that there are no adequate means for combating the overheating that can occur in homes in summer when they do not have cooling appliances or the resources for covering the cost of using them. Nonetheless, the definition of energy poverty does include this situation because ‘basic energy needs are not met’ (Ministerio para la Transisción Ecológica, 2019).

Table 13 below analyses the shortcomings detected when applying the methodology to the case study and the possible measures to be taken to address them.

Table 13. Shortcomings identified in applying the methodology to the case study and possible measures to be taken to address them.

Shortcoming	Proposal for improvement	Difficulties	Support needed to overcome difficulties
Excessive heating demand	Energetic rehabilitation of the envelope	High price of investment Difficulty of management due to it being a collective property in a vulnerable socio-economic area	Economic incentives by the administration depending on the income and savings capacity of the recipients Specific assistance in the processing and implementation of the proposal for improvement for vulnerable groups
Excessive demand for DHW	Incorporation of renewable energies		
Inadequate heating installation	Replace electric heating with gas heating	Moderately high price of investment	Economic incentives by the administration less than in the previous cases
		The gas heating installation presents a greater difficulty in controlling expenditure than electric heating	Establish a prepaid system and monitor the gas meter to provide real-time consumption data through a mobile application
High energy prices that make energy expenditure > 2M	Social tariff	The tariff structure penalises the fixed term of power contracted as opposed to the variable term of consumption carried out, which discourages energy saving measures	Reduce the fixed term of the bill and set a variable price for the consumption term, with a reduced price for basic consumption depending on the type of household and a penalised price for excess consumption
	Change the gas bill to a monthly periodicity and the payment date of both, gas and electric bills, to the first days of the month	This would help overcome the difficulties faced by low-income households in paying for supplies when they receive their income and so prevent them from spending scarce money on other needs	A simple legislative measure obliging the distribution companies would be sufficient to implement this measure

Buildings with better passive design reduce energy demand for heating by 13% compared to poorly designed buildings. Passive design is important for reducing energy demand but is not sufficient to eliminate energy poverty in the studied area.

If we take the data on the percentage of rental housing in the district of Carabanchel of 24% instead of the data of 5% collected in the official statistics because these statistics do not collect housing rented outside the law, there is a significant difficulty in adopting energy saving measures in buildings: the lack of incentive for an owner to make an investment whose benefits are enjoyed by the tenants.

The social worker reports the existence in the neighbourhood of buildings that do not pay their community fees, that do not have the obligatory insurance, that do not pay for the maintenance of the elevators, including some cases in which the water supply to the building has been cut off for lack of payment. In these cases of most extreme vulnerability, it is impossible to consider improvements in a collective property whose management is neglected and whose payments are not made even for the most basic issues.

In cases where the owner of the property is still the Madrid Housing Institute, it would be possible to consider an intervention in the building by the administration as a subsidiary civil liability to provide better living conditions. However, in the current situation, the public treasury is not choosing to make such investments to alleviate energy poverty either.

What is decisive in the case study in which the proposed methodology has been applied is that the households that have a gas heating installation are out of energy poverty while the households that have an electrical heating installation are in a situation of energy poverty.

The social worker reports that vulnerable people in the neighbourhood she serves do not use the heat because they cannot afford it. Even in some cases where the house is humid, doctors have diagnosed that the respiratory problems of the inhabitants are due to the lack of habitability of the homes.

Even in households that have a gas heating system, this system is not used due to the difficulty of controlling expenditure, and the use of electric heating apparatus is chosen, despite having a higher cost. In addition, the boiler is a household appliance whose replacement represents a high cost for families with low income. It is more economical to buy a heating appliance or a thermo electric for DHW preparation. This difficulty aggravates the situation of energy poverty, since this requires paying more for the same heat.

The social worker reports that there have been difficulties with flat rates that allowed the same amount to be paid per month until the end of the year when the companies proceeded to regularize the situation by demanding payment of the excess consumption made. By paying the same amount every month, some families increased their consumption thinking that it would not mean an over-cost that finally appeared accumulated at the end of the year.

7. Conclusions

The objective indicators used by NSAEP (Ministerio para la Transisción Ecológica, 2019) to determine the existence of energy poverty that are based on the actual consumption of energy have limitations. In order to overcome these limitations, a methodology is suggested that takes into account the theoretical consumption of energy necessary for maintaining households within comfort limits.

This second approach needs to develop a methodology that is sufficiently simple to be able to study energy poverty at the urban level. This study moves forward in this direction by proposing a balanced methodology that takes into account all the elements that effect household energy consumption and gives them equal weight.

The suggested methodology was carried out in a case study, the Pan Bendito neighbourhood. The results obtained are within the range of values obtained by other studies which focused primarily on heating consumption (Kurtz, 2015) (Martín-Consuegra, 2019), but which carried out a greater in-depth investigation into other types of household energy consumption such as domestic hot water, cooking, lighting or appliances.

The influence of the quality of housing construction on energy poverty is observed, as previous studies have already observed (Oteiza, 2018) (Domínguez Amarillo, 2016) (Kurtz, 2015). The importance of correctly applying passive measure in the design of the houses is also quantified, despite the shortcomings of the thermal envelope.

After applying the proposed methodology to the case study and analysing the results obtained, it is concluded that the methodology is adequate for its purpose since, using the available data that are updated every year, it allows for the assessment of the fuel poverty situation at urban level of each census section.

To enable the use of the method in other cities in Spain and Europe (since the data used are available in that area) with different climatic characteristics, it is necessary to develop the Monsoon model used (Monzón, 2017), whose current development only allows its application to 29% of the Spanish population living in cities.

The rest of the data that needs to be obtained and the formulas that need to be used have no limitations when applying the proposed methodology for analysing energy poverty on an urban scale.

After contrasting the theoretical results of the application of the method with the social reality of the neighbourhood, several proposals susceptible of being carried out in the political sphere have been analyzed.

Water supply rates are available at a lower price for the first cubic metres, and it is desirable that this tariff structure be adopted in order to reduce the cost of reasonable consumption and penalize energy consumption that occurs once basic needs have been met.

This research can help to visualize energy poverty in the territory, which undoubtedly is a very useful tool in order to define policies to combat energy poverty specifically in each neighborhood.

With regard to future lines of research, the challenge of addressing the lack of studies in energy poverty remains. It is necessary to investigate the limits of what are considered to be basic energy needs and what is considered wasteful in greater depth. The size of the household, the number of users, the hours of use and the interior temperatures that are maintained are factors that influence energy consumption but do not always imply energy poverty.

Statements and Declarations

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Acknowledgements

All persons who have made substantial contributions to the work reported in the manuscript (e.g., technical help, writing and editing assistance, general support), but who do not meet the criteria for authorship, are named in the Acknowledgments and have given us their written permission to be named. If we have not included an Acknowledgments in our manuscript, then that indicates that we have not received substantial contributions from non-authors.

We would like to thank Raquel Rentero Lavín, social worker of the Pan Bendito social platform, for her contributions to this paper received through the interview conducted on 21 March 2020.

We would like to thank Fernando García de Frutos for downloading the catastral data for the 2,382 households analysed in this work.

References

Agencia Estatal de Meteorología AEMET. (2019). *Olas de calor cada vez más intensas y frecuentes.* Obtenido de http://www.aemet.es/es/noticias/2019/07/Olas_de_calor_mas_intensas_y_frecuentes

Asociación la Rueca. (2018). *Diagnosis participada. Abrantes (Carabanchel).* Obtenido de https://www.dropbox.com/s/buv7d3bpiibi044/Diagnostico%20comunitario%20Abrantes_2018.docx.pdf?dl=0

Atecyr. (2010). *Guía técnica. Agua caliente sanitaria central.* Madrid: IDAE.

Ayuntamiento de Madrid. (2009). *Planes de barrio 2009-2012. Pan Bendito.* Obtenido de https://www.madrid.es/UnidadesDescentralizadas/UDGParticipacionCiudadana/Planes_Barrio/2009-2012/05_Pan_Bendito/Caracteristicas_ Actuaciones_2009-2012_Pan-Bendito.pdf

Ayuntamiento de Madrid. (2014). *Estado de desarrollo de los ámbitos del Plan General a 1 de enero de 2014. CARABANCHEL.* Obtenido de https://www.madrid.es/UnidadesDescentralizadas/UrbanismoyVivienda/Urbanismo/PUBLICACIONES/Evoluci%C3%B3n/EstadoDesarrollo/11_Carabanchel.pdf

Ayuntamiento de Madrid. (2017). *Áreas de Información Estadística.* Obtenido de http://www-2.munimadrid.es/CSE6/control/seleccionDatos?numSerie=9040100012

Ayuntamiento de Madrid. (2017). *Distritos en cifras (Información de Barrios).* Obtenido de https://www.madrid.es/portales/munimadrid/es/Inicio/El-Ayuntamiento/Estadistica/Distritos-en-cifras/Distritos-en-cifras-Informacion-de-Barrios-/?vgnextfmt=default&vgnextoid=0e9bcc2419cdd410VgnVCM2000000c205a0aRCRD&vgnextchannel=27002d05cb71b310VgnVCM10000

Ayuntamiento de Madrid. (2017). *Mapas de distritos y barrios. Distrito 11 Carabanchel.* Obtenido de https://www.madrid.es/UnidadesDescentralizadas/UDCEstadistica/Nuevaweb/Territorio,%20Clima%20y%20Medio%20Ambiente/Territorio/Mapas%20de%20dist%20y%20bar/Carabanchel/Distrito%2011%20-%20Carabanchel.pdf

Ayuntamiento de Madrid. (2019). *Estudio sociodemográfico de los barrios de Madrid ligados a los Planes Integrales de Barrio-PIBA.* Obtenido de https://www.madrid.es/portales/munimadrid/es/Inicio/El-Ayuntamiento/Estudio-sociodemografico-de-los-barrios-de-Madrid-ligados-a-los-Planes-Integrales-de-Barrio-PIBA-2019-/?vgnextfmt=default&vg nextoid=986c96daadc0b610VgnVCM1000001d4a900aRCRD&vgnextchannel

Boardman, B. (1991). *Fuel Poverty: From Cold Homes to Affordable Warmth.* London: Bellhaven Press.

Bouzarovski, S. &. (2017). Spatializing energy justice. *Energy Policy*(107), 640-648.

Bradshaw, J. &. (1983). Social Policy Options and Fuel Poverty. *Journal of Economic Psychology, 3-4*(3), 249-266.

Centro Nacional de Energías Renovables. (2016). *Guía idae: Manual de usuario de calificación energética de edificios existentes CE3X.* Madrid: IDAE.

Comunidad de Madrid. (1998). *Nueva Línea 11. Tramo: Plaza Elíptica-Pan Bendito.* Obtenido de https://www.comunidad.madrid/servicios/transporte/nueva-linea-11-tramo-plaza-eliptica-pan-bendito

De Luxán García de Diego, M. S.-G. (2017). *Re-habilitación exprés para hogares vulnerables. Soluciones de bajo coste.* Madrid: Fundación Gas Natural.

Department of Energy and Climate Change (DECC) & Building Research Establishment (BRE). (2019). *Fuel Poverty Methodology Handbook.* Obtenido de https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/829010/Fuel_Poverty_Methodology_Handbook_2019.pdf

Dirección General del Catastro. (2019). *Difusión de datos catastrales.* Obtenido de https://www.sedecatastro.gob.es

Domínguez Amarillo, S. S. (2016). *La envolvente energética de la vivienda social. El caso de Sevilla, 1939-1979.* Madrid: Consejo Superior de Investigaciones Científicas.

European commission. (2017). *Proposal for a Directive of the European Parliament and of the Council on common rules for the internal market in electricity (recast) COM/2016/0864 final/2 - 2016/0380 (COD).* Brussels.

Eurostat. (2017). *Energy consumption in households.* Obtenido de https://ec.europa.eu/eurostat/statistics-explained/index.php/Energy_consumption_in_households#Energy_consumption_in_households_by_type_of_end-use

Eurostat. (2017). *Estadísticas de los precios de la electricidad.* Obtenido de https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Electricity_price_statistics/es#Precios_de_la_electricidad_para_los_consumidores_dom.C3.A9sticos

Eurostat. (2017). *Precios del gas natural para los consumidores domésticos.* Obtenido de https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Natural_gas_price_statistics/es#Precios_del_gas_natural_para_los_consumidores_dom.C3.A9sticos

Fowler, T. S. (2015). Excess winter deaths in Europe: a multi-country descriptive analysis. *The European Journal of Public Health, 2*(25), 339-345.

Gallego Sánchez-Torija, J. (2018). La auditoría energética operativa en centros docentes como herramienta para mejorar el ahorro y la eficiencia energética. . Doctoral dissertation.

García Montes, J. M. (2011). *Síntesis del Estudio Parque de Bombas de Calor en España.* Madrid: IDAE.

Grupo de Termotecnia de la Escuela Superior de Ingenieros Industriales de la Universidad de Sevilla. (2009). *Escala de calificación energética para edificios de nueva construcción.* Madrid: Instituto para la Diversificación y Ahorro de la Energía.

Healy, J. D. (2003). Excess winter mortality in Europe: a cross country analysis identifying key risk factors. *Journal of Epidemiology & Community Health, 10*(57), 784-789.

Hernández Aja, A. R. (2018). *Barrios vulnerables de las grandes ciudades españolas. 1991/2001/2011.* Madrid: Instituto Juan de Herrera. Departamento de Urbanística y Ordenación del Territorio. Universidad Politécnica de Madrid.

Hernández Aja, A. V. (2012). *Análisis urbanístico de Barrios Vulnerables.* Madrid: Instituto Juan de Herrera.

Hills, J. (2012). *Getting the Measure of Fuel Poverty: Final Report of the Fuel Poverty Review.* London: Centre for Analysis of Social Exclusion.

IDAE. (2011). *Proyecto SECH-SPAHOUSEC. Análisis del consumo energético del sector residencial en España. Informe Final.* Madrid: IDAE.

Instituto de Estadística de la Comunidad de Madrid. (2019). *Nomenclátor oficial y callejeo.* Obtenido de http://www. madrid.org/nomecalles/Inicio.icm

Instituto Nacional de Estadística. (2011). *Microdatos. Censo de población 2011.* Obtenido de https://www.ine.es/censos2011_datos/cen11_datos_microdatos.htm

Instituto Nacional de Estadística. (2017). *Atlas de Distribución de la Renta de los Hogares 2017.* Obtenido de https://www.ine.es/experimental/experimental.htm

Instituto Nacional de Estadística. (2017). *Encuesta de condiciones de vida 2017. Resultados definitivos.* Obtenido de https://www.ine.es/CDINEbase/consultar.do?mes=&operacion=Encuesta+de+condiciones+de+vida&id_oper=Ir&L=0

Instituto Nacional de Estadística. (2017). *Encuesta de Presupuestos Familiares (Base 2006). Año 2017.* Obtenido de https://www.ine.es/CDINEbase/consultar.do?mes=&operacion=Encuesta+de+Presupuestos+Familiares&id_oper=Ir&L=0

Kurtz, F. M.-M. (2015). Obsolescencia de la envolvente térmica y acústica de la vivienda social de la postguerra española en áreas urbanas vulnerables. El caso de Zaragoza. *Informes de la Construcción, Extra-1*(67), m021.

Kyprianou, I. S. (2019). Energy poverty policies and measures in 5 EU countries: A comparative study. *Energy and Buildings*(196), 46-60.

Lelkes, O., & Zólyomi, E. (2015). Improvement during crisis years? Poverty and housing conditions across the EU. Viena: Eropean Centre.

López de Lucio, R. (2007). *Construir ciudad en la periferia. Criterios de diseño para áreas residenciales sostenibles.* Madrid: Mairea.

Martín, M. (14 de March de 2010). *Los siete pecados capitales de Pan Bendito.* Obtenido de https://elpais.com/diario/2010/03/14/madrid/1268569454_850215.html

Martín-Consuegra, F. H.-A. (2019). Distribución de la pobreza energética en la ciudad de Madrid (España). *EURE Revista de Estudios Urbano Regionales, 135*(45), 133-152.

Ministerio de Fomento. (10 de September de 2013). Orden FOM/1635/2013, de 10 de septiembre, por la que se actualiza el Documento Básico DB-HE «Ahorro de Energía», del Código Técnico de la Edificación, aprobado por Real Decreto 314/2006, de 17 de marzo. *Boletín Oficial del Estado*(219), 67137-67209.

Ministerio de Obras públicas y urbanismo. (18 de June de 1984). REAL DECRETO 1133/1984, de 22 de febrero, sobre actuaciones de remodelación y realojamiento en determinados barrios de Madrid. *Boletín Oficial del Estado*(145), 17805 - 17814.

Ministerio de transportes, movilidad y agenda urbana. (2011). *Atlas de la vulnerabilidad la Vulnerabilidad Urbana.* Obtenido de https://www.mitma.es/areas-de-actividad/arquitectura-vivienda-y-suelo/urbanismo-y-politica-de-suelo/observatorio-de-la-vulnerabilidad-urbana/atlas-de-la-vulnerabilidad-urbana/atlas-de-las-vulnerabilidad-urbana-en-espan%CC%83a

Ministerio para la Transisción Ecológica. (2019). *Estrategia nacional contra la pobreza energética 2019–2024.*

Monzón, M. L. (2017). Simplified model to determine the energy demand of existing buildings. Case study of social housing in Zaragoza, Spain. *Energy and Buildings*(149), 483-493.

Moore, R. (2012). Definitions of fuel poverty: Implications for policy. *Energy policy*(49), 19-26.

Moya González, L. (1983). *Barrios de promoción oficial Madrid 1939–1976. La política de promoción pública de vivienda.* Madrid: COAM.

National Energy Action (NEA) and Energy Action Scotland (EAS) National Energy Action. (2019). *UK Fuel Poverty Monitor 2018-2019*. Obtenido de https://www.nea.org.uk/wp-content/uploads/2019/09/Fuel-poverty-monitor-high-res.pdf

Oteiza, I. A.-C. (2018). *La envolvente energética de la vivienda social. El caso de Madrid en el periodo 1939-1979.* Madrid: Consejo Superior de Investigaciones Científicas.

Parés, N. E. (2015). *Perfil de consum energètic de la població atesa per Serveis Socials a Sabadell.* (A. d. Sabadell, Ed.) Obtenido de http://ca.sabadell.cat/Energia/d/articleprestacionsE2015.pdf

Rademaekers, K. Y. (2016). *Selecting indicators to measure energy poverty.* Rotterdam: Trinomics.

Rodríguez Villasante, T. A. (1989). *Retrato de chabolista con piso: Análisis de redes sociales en la remodelación de barrios de Madrid.* Madrid: IVIMA.

Romero, J. C. (2014). *Pobreza energética en España. Análisis económico y propuestas de actuación.* Vigo: Economics for Energy.

Romero, J. C. (2018). The policy implications of energy poverty indicators. *Energy policy*, 98-108.

Sareen, S. T. (2020). European energy poverty metrics: Scales, prospects and limits. *Global Transitions*(2), 26-36.

Serra Florensa, R. &. (1995). *Arquitectura y energía natural.* Barcelona: Ediciones UPC.

Thomson, H. S. (2018). *European Energy Poverty: Agenda Co-Creation and Knowledge Innovation (ENGAGER 2017-2021). The challenge of energy poverty measurement.*

Tirado Herrero, S., et al. (2016). *Pobreza, vulnerabilidad y desigualdad energética. Nuevos enfoques de análisis. España 2006-2016.* Madrid: Asociación de Ciencias Ambientales.

Tirado Herrero, S., et al. (2018). *Pobreza Energética en España. Hacia un sistema de indicadores y una estrategia de actuación estatal.* Madrid: Asociación de Ciencias Ambientales.

Tyk. (2016). *Carabanchel District Location Map, Madrid, Spain.* Obtenido de https://upload.wikimedia.org/wikipedia/ commons/c/c5/Carabanchel_District_loc-map_%282%29.jpg

Villalón, J. J. (2019). *Lugares vulnerables, violencias y delincuencia.* Madrid: Universidad Nacional de Educación a Distancia.

Zapatero Santos, M. A. (2017). Densidad urbana: Concepto y Metodología. Análisis Comparativo de los tejidos de Madrid. End of degree project.