REVERTER

Deep REnovation roadmaps to decrease households VulnERability to Energy poveRty

Project No. 101076277

Deliverable 3.2 – Identification of EP hotspots and capacity building needs

Due date:	31/10/2023
Dissemination level:	PU - Public
Lead beneficiaries:	ISR/NTUA
Contributing beneficiaries:	All

Co-funded by the European Union

About this document

This deliverable provides the results of the analysis conducted for the identification of EP hotspots and the assessment of vulnerable consumers' capacity needs.

Status of deliverable	By	Date
Submitted (Author(s))	Dimitris Damigos Sevastianos Mirasgedis Elpida Kalfountzou	31/10/2023
Verified (WP leader)	Christos Tourkolias	06/11/2023
Approved (Coordinator)	Dimitris Damigos	07/11/2023

Author(s)

Dimitris Damigos, Sevastianos Mirasgedis & Elpida Kalfountzou, NTUA

Paula Fonseca, Pedro Moura, ISR

Daniela Kostova, GSC

Argyro Giakoumi, Christos Tourkolias, CRES

Inês Cunha, Nuno Morais, CMC

Kristaps Kašs, Ekodoma

Ieva Kalniņa, Valters Liberts Muzikants, REA

Nikol Suleyman, Kristina Shopova, Bojidar Georgiev, BM

Vicky Tzega, EKPIZO

Disclaimer

Acknowledgement

This document is a deliverable of the REVERTER project. This project has received funding from the European Union's LIFE programme under grant agreement No 101076277.

Executive summary

The findings of this deliverable serve, at project level, as input for ongoing/future tasks of the project and, at a broader level, as a guide and inspiration for future research and improvements in EP diagnosis.

At the project level, secondary and primary data were analysed in order to determine the levels of energy poverty in each pilot area. Specifically, we investigated to what extent the characteristics of the buildings stock and the used heating and cooling systems, the local climatic conditions, the households' income and the respective energy expenditure, the households' knowledge and attitudes on energy use, the penetration of energy saving measures and the barriers of their implementation influence the energy poverty levels as well as the effectiveness of the policies implemented to tackle the problem. The specific characteristics identified in each pilot area, even at the cultural level, combined with the existing institutional framework and subsidised energy saving programmes will be exploited by the project partners for the finalisation of the roadmaps, the design of the OSSs, and the preparation of tailormade materials for community capacity building programmes.

The analysis provides also valuable insights that can help to address one of the most important challenges that the European Union and its Member States face in the fight against EP, namely the identification of households that are in or at risk of EP and need to be assisted. The main problems currently encountered in this effort relate to the characteristics of the indicators used and their data collection framework. The main indicators currently applied to measure EP levels at European and national level (very few countries have official national indicators to measure the phenomenon) are the inability to keep the home adequately warm, the arrears on utility bills, and the total population living in a dwelling with a leaking roof, damp walls, floors or foundation, or rot in window frames or floor. Actually, these three indicators, together with the at-risk-of-poverty rate are required to be considered by the Member States when assessing the share of energy poverty in their national energy and climate plans [Article 8 of Directive 2023/1791 of 13 September 2023 on energy efficiency and amending Regulation 2023/955 (recast)].

These indicators, calculated and published annually by the EU SILC, play a pivotal role in measuring and comparing EP levels within and across the Member States and evaluating the efficacy of policies aimed at its alleviation. However, the identification of EP households faces certain limitations. Primarily, these indicators rely on perceived EP levels. To mitigate subjectivity concerns, alternative expenditure-based indicators have been introduced by the European Observatory on Poverty and Social Exclusion (EPOV) and its successor, the European Observatory on Energy Poverty (EPAH). However, these indicators are calculated by HBS data, available for select years and limited to specific Member States. A more significant limitation arises from the fact that the three consensual can only be estimated through questionnaire surveys. Consequently, EP conditions are ascertainable solely for households within the survey's sampling framework. Compounding this issue, the EU SILC lacks vital information related to EP, such as dwelling energy performance, area, and certain household characteristics.

In response to these challenges, Member States predominantly focus on identifying households at risk of EP from a financial perspective. This approach, however, represents a notable shortcoming, as it overlooks the distinction between income and fuel poverty - two distinct problems necessitating tailored policy solutions. For instance, some Member States employ criteria from the social welfare system to define energy vulnerable households. Hence, in some cases where recipients of the electricity social tariff, deemed eligible by social welfare criteria, may not align with the definition of energy poverty according to headline indicators, and vice versa. The differences between income and energy poverty underscores the need for a more nuanced and comprehensive framework that encompasses both social welfare considerations and specific energy-related challenges and goes beyond pure financial metrics. At the same time, this framework should help policymakers to identify energy-poor households using objective and readily available data, thereby reducing dependence on questionnaire surveys and self-reported indicators.

REVERTER attempted to address these challenges by using (and testing) state-of-the-art tools in EP analysis and prediction and by developing new EP indicators.

Regarding the methodological tools, REVERTER used spatial representation and analysis of selected EP indicators and primary drivers (namely income and house energy efficiency risk), multivariate logistic regression models to examine the relationship between selected EP indicators and commonly referred EP drivers, and Machine Learning Algorithms (MLAs) to explore whether it is possible to identify EP households with a fairly high degree of accuracy using a small set of variables, easily retrievable from relevant government agencies without resorting to social surveys. These methodological tools were tested only in the Athens Urban Area because suitable data were not available for the other pilots. The main strengths and weaknesses of these tools are highlighted hereinafter.

EP mapping has the capability to identify areas at highest risk of EP. As a result, the creation of local EP maps can assist local and national authorities in strategically directing interventions from a spatial perspective. This could ensure a coherent and holistic approach to addressing EP at the household level, create potential to catalyse large-scale energy retrofit programmes, and consequently reduce associated costs and enhance the overall cost-effectiveness of EP alleviation policies and programs. On the other hand, it is a data-demanding approach, if the analysis must be conducted at neighbourhood or block level to be meaningful. For instance, in the Athens Urban Area the analysis was based on zip code aggregated data and certain areas of the pilot remained unexplored due to lack of observations. Yet, it is noted that state authorities and governmental agencies have access to confidential housing and socioeconomic spatial microdata (e.g., evidence from tax returns, building characteristics from censuses or databases of Building Energy Performance Certificates, etc.) that would help to create the relevant EP maps at block or even building level.

Multivariate analysis provides valuable insights into the impact of sociodemographic and housing characteristics on EP. Specifically, it elucidates the associations between EP drivers (explanatory variables) and indicators (dependent variable). Regression models serve not only to scrutinize the sign and significance of relationships but also to establish a predictive model for EP risk based on the values of explanatory variables. However, this method is not without challenges. Developing a robust model necessitates meeting certain conditions. Foremost and crucially, the dataset should include information on critical parameters, and ample, representative sample sizes are essential for obtaining unbiased estimates. For example, as highlighted in Section 3.3.2, regression models for EU SILC indicators exhibited poor performance due to the omission of vital variables. Furthermore, the predictive accuracy of models may be compromised by fluctuations in the values of factors influencing the phenomenon but not accounted for in the model. For instance, changes in energy prices could escalate both real and theoretical required energy expenditures, compelling more households into EP. In such cases, regression parameters would also be affected. This underscores why a pooled sample, covering a 5-year period, was employed in this study instead of constructing separate annual models.

Machine learning (ML), a subset of artificial intelligence (AI), has the potential to directly enhance the identification of EP households and, thereby enabling more precise allocation of targeted assistance. Enhanced identification of EP households is posited to yield significant benefits, including potential net energy savings and emissions reductions, particularly if households consume energy at levels conducive to satisfying energy service requirements. Alternatively, improved energy services could ensue if households are currently under-consuming energy. These positive outcomes are associated with the prospect of a higher number of EP households benefiting from social assistance, contingent upon a more efficient identification process, assuming that public funds remain constant. The latter underscores the significance of carefully examining the dynamic relationship between climate policies and energy affordability, particularly regarding its potential impact on vulnerable households in countries with limited fiscal resources. More crucially, it emphasises the necessity of seamlessly integrating energy poverty into the formulation of climate policies, strategies for climate transition, and overarching climate ambitions. Additionally, predictive models based on ML algorithms can significantly reduce the time and cost required for identifying EP households. This efficiency leads to a more judicious use of existing resources. Furthermore, these models contribute to the design of more effective energy efficiency schemes by providing a deeper understanding of the factors that exert the most influence in determining whether a household is, in practice, EP. This heightened understanding enables the development of targeted strategies to address the root causes of EP, making interventions more precise and impactful. The findings of the ML model tested in REVERTER are encouraging. It is proved that using a small number of variables it is possible to identify energy-poor households with a fairly high degree of accuracy. It should be noted, however, that the ML model was trained and applied in a specific area in terms of climatic conditions and with relatively uniform housing characteristics. It is therefore an open question whether it is feasible to successfully train a ML model with a limited number of variables (including for example only heating/cooling degree days as additional variables) on a larger geographical scale, for example at country level. Moreover, ML like any other tool, confronts several challenges. The predictive efficacy of ML models is notably contingent on the quality and comprehensiveness of the underlying data and features, i.e., the accuracy of ML models is constrained by limited data availability. Another notable challenge is the potential for biases within the underlying datasets, either against specific subgroups or in failing to fully represent the broader population under consideration. This can result in unfair outcomes and misrepresentations of the actual dynamics, especially when certain groups are underrepresented or systematically excluded. Last but not least, it is essential to acknowledge the practical limitation that creating an ML model entirely free of false negatives – i.e., instances where households in EP are inaccurately classified as not in EP by the model – is not practically feasible.

Apart from the methodological tools, REVERTER introduced alternative EP indicators, e.g., the Weighted and Simple Composite Indices, the modified NEPI, the modified LIHC and the simplified LILEE. Of broader interest are the last two indicators, namely the modified LIHC and the simplified LILEE (the Weighted and Simple Composite Indices are combinations of the widely used EU SILC's consensual indicators and the modified NEPI is a variation of the officially established EP indicator used in Greece).

The modified LIHC is a variation of the UK's LIHC indicator. The REVERTER's modified LIHC indicator classifies a household as experiencing EP if its equivalised residual income falls below 60% of the equivalised median national income. This index is derived by subtracting 60% of the equivalised simulated energy costs (necessary to ensure adequate energy services to the household) from the equivalised total income of the household. The estimated energy costs are based on KENAK's (the Greek Regulation of Energy Performance of Buildings) theoretical required energy consumption. However, only 60% of the theoretical required energy consumption is considered. This adjustment accounts for the finding in Greece that real energy consumption tends to be 60% of the theoretically estimated needs. Importantly, unlike the UK's LIHC, housing costs are not subtracted from income in this modified LIHC calculation. The analysis of the Greek pilot data and results from previous surveys reveal a notable pattern: house owners paying a mortgage are significantly under-represented in energy poverty indicators across Europe. This phenomenon is attributed to the rigorous credit checks conducted by financial institutions before granting mortgage loans. Thus, this tenure group possesses sufficient available resources to access the mortgage market, they appear to be less impacted by energy poverty. To prevent distortions, the proposed indicator refrains from deducting even rental costs. However, the indicators allows for the application of correction factors (i.e., multipliers) to the estimated residual income to account for specific household categories (e.g., single-parent families, tenants paying market-rate rent, etc.).

The suggested indicator boasts two primary advantages. Firstly, it relies solely on objective datasets that encompass the three main drivers of EP: the energy efficiency of dwellings, energy costs, and household income. Notably, it circumvents the need for collecting questionnaire data, as information on dwelling characteristics can be sourced from Building Censuses and/or databases of Building Energy Performance Certificates, and income data can be retrieved from tax authorities. On the other hand, the modified LIHC necessitates the calculation of theoretically required energy costs. This calculation either relies on a set of assumptions, potentially compromising result accuracy, or demands the collection of detailed dwelling data, a process that is both time- and resource-intensive. Finding a balance between these considerations is imperative for optimal results.

In an effort to avoid extensive calculations, REVERTER proposed a new indicator, namely the "simplified LILEE", which is a simplified version of the UK's Low Income Low Energy Efficiency (LILEE) indicator. Based on the simplified LILEE, a household is considered energy poor if its income is below 60% of the median income and if it resides in a low-energy class home. For the case of the Athens Urban Area pilot, in which the indicator was examined due to the availability of data, homes built before 1980 were considered "low-energy class", i.e., before the implementation of the first insulation regulation.

As discussed in Section 3.4, the simplified LILEE indicator is simple and effective and, most importantly, it allows for the identification energy-poor households residing in the least energy-efficient homes. In addition to its simplicity and effectiveness, the proposed indicator offers policymakers the ability to analyse various policy scenarios. The main limitation in the use of this indicator, at present, is that EU SILC survey does not include information on the age (or, if known, the energy class) of residences, and the HBS is not carried out on an annual basis in all EU countries and does not provide information on age of residence on a regular basis.

A final comment, which is of primary interest to EU officials and policymakers, concerns the data on which the calculations of the various indicators are currently based, primarily the EU SILC and

HBS data. With the exception of Hungary (Menyhert, 2023), data in all countries for the EU SILC and HBS are gathered from different population samples. Additionally, HBS data is available for select years (2010, 2015, and 2020) in only a few countries, presenting challenges that include:

- The Commission recommendation (EU 2020/1563) on EP outlines specific indicators and defines particular survey variables required for their calculation. These include consensual and expenditure-based indicators which are collected separately on either the SILC or the HBS data component. Consequently, they do not allow for a joint micro-level analysis and, thus, have limited comparability.
- Existing indicators lack the direct capacity to capture buildings' energy efficiency, thereby challenging the application of the "worst first" principle.
- Essential variables, such as the year of house construction and household characteristics, are absent from either EU SILC or HBS datasets.

To address these challenges, the following measures could be considered:

- Annual Implementation of HBS: Adopting a mandatory annual implementation of the HBS, aligning it with the EU SILC schedule.
- Enriching EU SILC variables: Augmenting the EU SILC dataset with critical variables for measuring energy poverty (especially if HBS is not implemented on an annual basis). This includes incorporating variables like the year of dwelling construction, energy class certification (if any), expenditure on electricity, gas, and other fuels, as well as demographic information such as the number of unemployed or economically inactive individuals in specific age groups (e.g., number of persons aged less than or equal to 4 and number of persons aged more than or equal to 65).
- Harmonizing common variables: Facilitating the harmonisation of common variables between EU SILC and HBS to ensure direct comparability. For instance, variables like HBS HY020 and EU SILC HH095 or HH099 are not directly comparable.
- Conducting a specialised survey along with the HBS every three years so as to obtain data about the energy performance and use of the utilised energy systems and equipment for all the end-uses (space heating, space cooling, domestic hot water, cooking, lighting and electric appliances), the potential implementation of energy efficiency interventions and the energy behaviour of the households.
- Fostering EP definitions that enable the bottom-up identification of EP households, by leveraging data from government services, such as tax offices, without necessitating primary questionnaire surveys.
- Ensuring the continuous monitoring of parameters that affect EP aiming at the potential improvement and readjustment of the overall framework.
- Facilitating the establishment of EP observatories to monitor the evolution of the energy poverty using different metrics.

These proposed measures could enhance the robustness, comparability, and comprehensiveness of the data used for EP analysis, offering more nuanced insights for effective policymaking at the EU level.

Table of Contents

List of Figures

List of Tables

Glossary

Abbreviation / acronym	Description
Vulnerable citizen/consumer	The term is used interchangeably throughout the document for individuals.
NECPs	National Energy and Climate Plans
LTRS	Long-Term Renovation Strategies
EP	Energy Poverty
EED	Energy Efficiency Directive
EPBD	Energy performance of buildings directive
OSS	One-stop shop
LCA	Life Cycle Assessment
EPOV	European Energy Poverty Observatory
EPAH	Energy Poverty Advisory Hub
EU-SILC	European Union Statistics on Income and Living Conditions
HBS	Household Budget Survey
GWh	Gigawatt Hours
RES	Renewable energy sources
RAs	REVERTER Ambassadors
NGOs	Non-governmental organisations
GDPR	General Data Protection Regulation
EAB	Ethics Advisory Board
SERTF	Sustainability, Exploitation and Replication Task Force
WCI	Weighted Composite Index
SCI	Simple Composite Index
NEPI	National Energy Poverty Index
LIHC	Low Income Hich Cost
LILEE	Low Income Low Energy Efficiency

1 Introduction

Diagnosing energy poverty (EP) is a crucial step in tackling the issue from both a top-down and bottom-up perspective. This process should be systematically implemented across various spatial scales to guide policymaking at different governance levels, be it central or local. The accurate identification of energy-poor populations and continuous monitoring of vulnerability levels are integral components of this diagnostic approach. Effectively diagnosing potential EP situations requires the use of indicators capable of reliably capturing its diverse facets. Given the complexity and multidimensionality of EP, a wide array of indicators and methodologies can be employed. The diagnostic process is inherently influenced by contextual factors, the availability of data, and the specific indicators selected for analysis. This contextual shaping of the diagnostic process is also underscored in the EPAH's Handbooks "A Guide to Understanding and Addressing Energy Poverty".

The results presented in the deliverable are useful at two different levels: internally, i.e., within the project, and more broadly. At the project level, the results provide a direct insight into energy poverty conditions in the four REVERTER pilots by analysing secondary data (e.g., from EU-SILC and HBS surveys) and primary information collected from the four social questionnaire-based surveys, using more than 10 existing and new/modified "tailor-cut" complementary indicators. Following the EU Energy Poverty Observatory's (EPOV) terminology, a former EU initiative for energy poverty that ran from 2017 to 2020, the indicators used are primary, i.e., they directly depict energy poverty. Moreover, this analysis serves as "market research" to identify key parameters (e.g., market, administrative, behavioural and informational barriers), which are necessary for the development of the roadmaps, the design of the OSSs, and the preparation of tailormade materials for community capacity building programmes on how to address the poor energy efficiency of dwellings.

At the broader level, a simple, yet effective methodology is proposed to better identify energy-poor and inefficient hotspots in vulnerable districts, clusters of buildings, in the context of the "worst first" principle. Moreover, secondary and primary data are analysed with state-of-the-art approaches, namely: statistical techniques (multivariate regression analysis to examine the relationship between EP indicators and EP drivers), machine learning algorithms, and spatial statistics. The aim of this effort is to develop indicators and/or approaches that allow central and local governments to determine not only the share of households in EP (or vulnerability) but also who these households are, as will be discussed in more detail in later sections. Although certain limitations exist (mainly due to data unavailability), the results are promising.

The rest of the document is structured, as follows: Section 2 discusses the methods and data sources used in the analysis. Section 3 analyses the main area, population and housing characteristics, as well as the EP situation in the REVERTER pilots (covering also the impacts of COVID-19 pandemic on household EP), illustrates the implementation of state-of-the-art tools and techniques in EP analysis and prediction and presents a simplified approach to identify energy-poor households in the context of the "worst first" principle. Section 4 summarises the results of the four social surveys towards assessing vulnerable consumers' capacity needs. Finally, Section 5 concludes with the main findings of the work.

To keep the main text concise and compact, the deliverable is accompanied by three Annexes. Annex I presents in more detail the characteristics and EP situation in the REVERTER pilots using data retrieved from existing databases. Annex II includes the complete analysis of the four social surveys conducted in the REVERTER pilots. Finally, Annex III provides the English version of the questionnaire used in the social surveys.

2 Methodological approach and data description

2.1 Methodological approach

In all pilots, a baseline assessment of EP conditions and characteristics was conducted. In this direction, data collected from existing databases (e.g., housing and population censuses from national statistical authorities, databases of energy performance certificates, EU-SILC and Household Budget surveys, etc.) were integrated and analysed to explore the main area (including climate and climate-driven energy consumption), population and housing characteristics, as well as the EP conditions.

Focusing on EP, the analysis was based on EU SILC and HBS datasets (as described in the next section, data availability differs across the four REVERTER pilots) for the years 2017-2021. Regarding EU SILC dataset, the analysis was carried out using the following EP indicators:

- EP1 - Leaking roof, damp walls/floors/foundation, or rot in window frames or floor (variable HH040) (available up to 2020)
- EP2 - Inability to keep home adequately warm (variable HH050)
- EP3 - Arrears on utility bills (once and twice or more) (variable HS021)
- EP4 - Arrears on utility bills (only once)
- EP5 - Arrears on utility bills (twice or more)
- EP6 - Weighted Composite Index 1: 0,25*HH040 + 0,5*HH050 + 0,25*HS021 (once and twice or more) (suggested by (Bouzarovski & Tirado Herrero, 2017) (available up to 2020)
- EP7 - Weighted Composite Index 2: 0,25*HH040 + 0,5*HH050 + 0,25*HS021 (only once) (modified version of Weighted Composite Index 1) (available up to 2020)
- EP8 - Weighted Composite Index 3: 0,25*HH040 + 0,5*HH050 + 0,25*HS021 (twice or more) (modified version of Weighted Composite Index 1) (available up to 2020)
- EP9 - Simple Composite Index 1: HH040 + HH050 + HS021 (once and twice or more) (available up to 2020)
- EP10 - Simple Composite Index 2: HH040 + HH050 + HS021 (only once) (modified version of Simple Composite Index 1) (available up to 2020)
- EP11 - Simple Composite Index 3: HH040 + HH050 + HS021 (twice or more) (modified version of Simple Composite Index 1) (available up to 2020)
- EP12 - Any form of EP (i.e., the household is defined as EP by any of the three main indicators HH040 or HH050 or HS021) (available up to 2020)

EP indicators 1, 2 and 3 are the most widely used and commonly acknowledged consensual-based indicators. The rest of the indicators are used to explore the depth of EP (e.g., EP indicators 6 to 11), specific aspects of EP (e.g., EP 4 and 5), or a "worst-case" scenario where energy-poor households are those facing any form of EP.

Expenditure-based EP indicators were calculated only for two pilots, namely Brezovo and Athens Urban Area, where HBS data were available for the period under investigation (i.e., for the years 2017-2021). The Bulgarian HBS dataset didn't include derived variables at household level referring to household size and type, equivalent size, number of persons per age class, number of persons who are working or are unemployed, etc. Therefore, four EP expenditure indicators were formed and calculated, based on previously used (e.g., the "10% rule") or modified (e.g., variations of 2M and M2 indicators) and other indicators suggested by scholars (e.g., the "25% threshold", a variation of the "FixThreshold" indicator proposed by (Menyhert, 2023). Specifically, the following indicators were calculated at national and pilot levels:

- Low Expense: households whose absolute level of energy expenditures (HE045) is less than half the national median.
- High Expense: households whose energy expenditure-to-income ratio is more than twice the national median (HE045 and HH099).
- 10% rule: households whose absolute level of energy expenditure (HE045) is more than 10% of their income (HE099).
- 25% threshold: households whose energy expenditure (HE045) exceeds 25% of total expenditures (HE00).

As far as the Greek pilot is concerned, the following expenditure-based EP indicators were initially estimated:

- The 2M indicator, which identifies as energy poor the households whose share of energy expenditure in income is more than twice the national median. To calculate this indicator both energy expenditures and income have been equivalized to consider the differences in a household's size and composition.
- The M/2 indicator, which identifies as energy poor the households whose absolute energy expenditure is below half the national median or, in other words, abnormally low. As previously the energy expenditure has been equivalized.
- The national energy poverty index (NEPI), according to which a household is classified as energy poor if the following two conditions apply simultaneously: (i) the annual cost of the total final energy consumed by the household is lower than the 80% of the expenditures theoretically required to cover the minimum final energy consumption of this household, and (ii) the total equivalized income of the household, which is influenced by the household's size and composition and calculated using the modified OECD equivalence scale, is lower than the 60% of the median equivalized income of all households in Greece, according to the definition of relative poverty.

It is worth mentioning that the structure of the NEPI incorporates key dimensions of the EP problem, namely, the discrepancy between consumed and required energy to ensure adequate internal thermal conditions in homes as well as households' income. However, a key point of criticism for the NEPI is the ambiguity in defining the minimum required energy consumption that is used in developing the condition (i) of the adopted definition. In addition, the identification of energy poor households requires a complex calculation process and particularly the calculation of the minimum required energy consumption of the residence, which obviously depends on its characteristics, the level of thermal insulation, the climatic conditions, etc.

Aiming to overcome these problems, two new energy poverty indicators were formulated in the context of this analysis:

- The **modified NEPI** index, which has the same structure as the NEPI and differs only in terms of condition (i), where in order to classify a household as energy poor, the annual

cost of the household's energy consumption must be lower than 60% of the expenditures associated with the theoretical required energy consumption of its dwelling as determined by the national Regulation of Energy Performance of Buildings (KENAK).
- The **modified LIHC** (Low Income Hich Cost) index that classifies as energy poor a household with equivalised residual income less than 60% of the equivalised median residual income of all Greek households. The index is obtained by deducting the 60% of equivalised estimated energy costs[1] required to ensure adequate energy services in its dwelling based on KENAK theoretical required energy consumption from the equivalised total income of the household.

Moreover, in an attempt to avoid extensive calculations, the application of a simplified form of the LILEE (Low Income Low Energy Efficiency) indicator **("simplified LILEE"**) was examined. Based on this proposed simplified indicator, a household is considered energy poor if its income is below 60% of the median income and if it resides in a low-energy class home. For the case of the Athens Urban Area pilot, in which the indicator was examined due to the availability of data, homes built before 1980 were considered "low-energy class", i.e., before the implementation of the first insulation regulation.

Besides descriptive statistics (e.g., univariate and bivariate analysis for measures of central tendency, variability, and frequency distribution), state-of-the-art approaches were employed, namely: (a) statistical techniques (multivariate regression analysis to examine the relationship between EP indicators and EP drivers), (b) spatial analysis and statistics for mapping EP hotspots and uncovering numerical spatial relationships, and (c) machine learning algorithms for the identification of EP households (the latter were tested and verified using data gathered by the questionnaire-based Greek social survey). Finally, recognising the need for an approach simple enough to be useful, yet robust enough to be meaningful so as to contribute to EP identification in the context of the "worst first" principle, a simplified version of the UK's Low Income Low Energy Efficiency indicator is proposed.

Moreover, to gain direct insight into real field situations in the selected pilot areas, four questionnaire surveys were implemented aiming to:

- recognise key incentives and barriers to energy retrofitting and, thus, facilitate the development of roadmaps,
- identify best practices in delivering energy advising through the physical and digital OSSs and the local engaging initiatives/campaigns,
- develop tailor-made materials, which will be used by the RAs and the OSS staff for community capacity building programmes, and
- recruit households willing to participate in REVERTER's field activities, e.g., home visits

The four surveys used a common questionnaire as a basis, but with some adaptations to the specific circumstances of each pilot. In general, the questionnaires focused mainly on house and heating/cooling system characteristics, energy costs and habits, information about the

---

[11] The 60% of the theoretical required energy consumption is used to take into account that real energy consumption has been found to be 60% of theoretical estimated needs in Greece. Also, energy costs are divided by the equivalisation factors used in the UK LIHC indicator, in order to produce equivalised energy costs. For details see: Table 2.1, p. 52. https://sticerd.lse.ac.uk/dps/case/cr/casereport72.pdf

implementation of energy efficiency interventions, energy vulnerability, and energy retrofit-related barriers. In addition to these questions, typical demographic information was collected. The English version of the survey questionnaire is provided in Annex III.

The questionnaires were self-administered (delivered online or through email) and researcher-administered (i.e., face-to-face interviews), as detailed in the relevant sections. Regardless the survey administration method, particular attention was given to ethical and data protection considerations ensuring compliance with GRDP.

Towards assessing EP by the social surveys, several expenditure-based and consensual indicators were calculated (the EP indicators used per pilot are not the same), as follows:

1. Condensation on windows and walls during winter
2. Inability to keep home adequately warm
3. Inability to keep home adequately cool
4. Arrears in energy bills over the last 12 months
5. Electricity/gas supply disconnections in the last 12 months
6. Central heating suspension by decision of a general meeting of the building or due to non-payment of common charges
7. Health problems due to inadequate heating or moisture
8. A composite consensual indicator calculated as follows:

   Composite indicator = Health problems*0.25 + (Inability to keep house cool+ Inability to keep house cool warm)*0.25 + Disconnections*0.25 + Arrears in bills*0.15 + Condensation*0.10

   This indicator receives values from 0 to 1; energy poor households are those having value greater than 0.5.

9. The ‘Ten-Percent-Rule’
10. The 2M indicator
11. The M/2 indicator
12. A ‘local’ 2M indicator (i.e., based on median energy expenditure of the sample)
13. A ‘local M/2 (i.e., based on median energy expenditure of the sample)
14. A quantile-based ‘Low income/High energy cost’ using equivalised income and equivalised energy costs, respectively. To calculate this indicator the quantiles of equivalised income and equivalised energy costs were used.
15. A quantile-based ‘Low income/Low energy efficiency’ based on five energy efficiency classes (which were based on the existence of energy saving measures), and the four categories of equivalised income.

2.2 Data sources and description

As mentioned, the analysis of the current situation of EP of the population in the four REVERTER pilots was based on Eurostat's EU SILC and HBS datasets. More details for each pilot area are provided hereinafter.

In the **Brezovo pilot** the analysis implemented data from the EU SILC and HBS surveys. Specifically, the National Statistical Institute of the Republic of Bulgaria provided EU SILC survey microdata (at household level) for the years 2017-2021 and HBS data for the years 2017-2019 and 2021. Nevertheless, the HBS data didn't include derived variables at household level referring to household size and type, equivalent size, number of persons per age class, number of persons who are working or are unemployed, etc. From the dataset, the observations selected were those that referred to region BG42 (variable DB040) and degree of urbanisation 3 (variable DB100 - rural area/thinly populated area). This subset of the data includes other areas than Brezovo, but with similar characteristics. The number of observations per year is presented in the following tables.

Table 1. Number of observations per year for the Brezovo pilot – EU SILC

Year	Frequency	Percent
2017	1151	20.7
2018	1127	20.3
2019	1106	19.9
2020	1063	19.1
2021	1117	20.1
Total	**5564**	**100.0**

Table 2. Number of observations per year for the Brezovo pilot – HBS

Year	Frequency	Percent
2017	194	24.9
2018	193	24.8
2019	198	25.4
2021	194	24.9
Total	**779**	**100.0**

The analysis in the **Athens Urban Area pilot** was based on EU SILC and HBS data, which were retrieved by the Hellenic Statistical Authority. The EU SILC and HBS survey microdata (at household level) were provided for the years 2017-2021. From the dataset, the observations selected were those that referred to region EL30 (variable DB040) and degree of urbanization 1 (variable DB100 - cities/densely populated area). The number of observations per year is presented in the following tables.

Table 3. Number of observations per year for the Athens pilot – EU SILC

Year	Frequency	Percent
2017	3609	27.4
2018	3663	27.9
2019	2189	16.6
2020	1873	14.2
2021	1817	13.8
Total	**13151**	**100.0**

Table 4. Number of observations per year for the Athens pilot – HBS

Year	**Frequency**	**Percent**
2017	2249	20.7
2018	2270	20.9
2019	2054	18.9
2020	2173	20.0
2021	2133	19.6
Total	**10879**	**100.0**

The analysis in **Riga pilot** about the energy poverty rates was based solely on data from Eurostat's EU SILC survey, which were downloaded by the Portal of the Official Statistics of Latvia. The EU SILC survey microdata (at household level) were available for the years 2017-2021. From the dataset, the observations selected were those that referred to Riga region (variable reg) and urban territory (variable laupil). The number of observations per year is presented in the following table.

Table 5. Number of observations per year for the Riga pilot – EU SILC

Year	**Frequency**	**Percent**
2017	1907	21.2
2018	1799	20.0
2019	1461	16.2
2020	1853	20.6
2021	1993	22.1
Total	**9013**	**100.0**

Finally, the analysis **Coimbra pilot** was based only on data from Eurostat's EU SILC survey. The Statistics Portugal provided EU SILC survey microdata (at household level) for the years 2017-2021. Nevertheless, for 2017 there was no separation into NUTS2 regions. For this reason, the final dataset included observations for the years 2018-2021. From this dataset, the observations selected were those that referred to region PT16 (variable DB040) and degree of urbanization 2 (variable DB100 - towns and suburbs/intermediate area). This subset of the data includes other areas than Coimbra, but with similar characteristics. The number of observations per year is presented in the following table.

Table 6. Number of observations per year for the Coimbra pilot – EU SILC

Year	**Frequency**	**Percent**
2018	790	28.4
2019	758	27.3
2020	617	22.2
2021	615	22.1
Total	**2780**	**100.0**

As regards the social surveys, the sample sizes by pilot area (those who followed the survey and those who competed it) are summarised in the following table.

Table 7. Social surveys sample sizes by pilot area

Pilot area	**Households followed the survey**	**Households completed the survey**
Brezovo	350	300
Athens Urban Area	754	496
Riga	935	445
Coimbra	462	299
Total	**2501**	**1540**

3 Identification of EP hotspots in REVERTER pilots

3.1 Climate, living and housing conditions

For conciseness reasons, this section summarises the main characteristics of the four REVERTER pilots to provide an overview of factors related to EP. A more detailed analysis can be found in Annex I of this document. The four REVERTER pilots differ in their climate, population and building characteristics, as discussed hereinafter.

3.1.1 Area characteristics and climate

The **Municipality of Brezovo**, located at Eastern Central Bulgaria, has a total area of 465.41 km^2. The relief of Brezovo municipality is mixed, with low and medium-high mountain areas, plain territories and water areas. From a climate perspective, the municipality of Brezovo is located in the transitional-continental climate zone, a sub-region of the European continental region, with relatively warm summers and mild winters. The average annual air temperature varies between 12.6°C and 13.6°C. Average summer temperatures are between 26-27°C, and average winter temperatures about 7°C.

The **Athens Urban Area**, also known as "Athens - Piraeus Urban Complex", forms the core and centre of Greater Athens and stretches across the Attica Basin over an area of 412 km^2, in Attica, the highest-populated region in Greece. In the new "Athens - Attica Regulatory Plan" (L. 4277/2014, Government Gazette Issue 156A, 01/08/2014), the Athens Urban Area is referred to the "Athens - Piraeus Spatial Unit", and consists of 40 municipalities, 35 of which are located within 4 regional units of the former Athens Prefecture (North Athens, West Athens, Central Athens, South Athens), and 5 municipalities are located within the regional unit of the former Piraeus Prefecture. The climate of the Athens Urban Area is mild. The average annual temperature over the last 30 years (1991-2020) is 18.5°C (around 26-29°C in summer and 10°C in winter), the total annual precipitation is roughly 433 mm, and the average humidity is 61% (Founda & Pierros, 2021).

Riga, the capital of Latvia, is located in the central part of Latvia, on the southern coast of the Gulf of Riga of the Baltic Sea. Although the area of the city of Riga occupies only 0.5% of the total area of Latvia, the city is home to a third of the total population of Latvia, making it the largest city at the level of both Latvia and the Baltic States. The city is characterized by 41% of natural areas, of which 16% of waters and 25% of greenery and natural areas. The average air temperature is around 7°C. The coldest months typically are January, February and December, with an average temperature below 0°C, while in summer the average temperature is around 17°C.

The Intermunicipal Community of **Coimbra** has an area of 4,335.57 km^2 and replaced, in 2013, the former Greater Metropolitan Area of Coimbra. The main city of the intermunicipal community is Coimbra, covering an area of 319.40 km^2. Located at an elevation of 40.19 m above sea level, Coimbra, like most of Portugal, has a warm Mediterranean climate, with mild, relatively rainy winters and hot summers. The city's annual average temperature is 16.8ºC (around 27°C in summer and 14°C in winter). Coimbra typically receives about 92.11 millimetres of precipitation and has 105.45 rainy days annually.

To illustrate the weather-related energy consumption for heating and cooling of buildings, the total heating degree days (HDD) and cooling degree days (CDD) indexes are presented in Table 8 and Table 9, respectively. The calculation of HDD relies on the base temperature, defined as the lowest daily mean air temperature not leading to indoor heating. Similarly, the calculation of CDD relies on the base temperature, defined as the highest daily mean air temperature not leading to indoor cooling. Data have been retrieved from Eurostat on NUTS3 level. In the HDD and CDD calculations, the base temperature is set to a constant value of 18°C and 21°C, respectively (Eurostat, 2023a).

Riga has the highest energy needs for heating (almost three times as high as in Athens and Coimbra), followed by Brezovo. On the other hand, Athens has by far the highest energy needs for cooling (two and four times higher than those in Brezovo and Coimbra, respectively). The cooling needs in Riga are significantly lower. Another point worth mentioning is the variability of HDDs and CDDs. For example, in Coimbra HDDs increased by around 27% in 2018 (year-to-year comparisons). In Riga, although relatively low, CDDs increased by around 855% in 2018 (year-to-year comparisons).

Table 8. Heating degree days in REVERTER pilots - annual data

	2017	2018	2019	2020	2021
Brezovo (based on Plovdiv NUTS3)	2,455.48	2,236.33	2,090.29	2,172.87	2,440.41
North Athens	1,250.28	1,044.87	1,178.80	1,194.26	1,191.55
West Athens	1,157.21	972.97	1,082.09	1,065.96	1,038.31
Central Athens	1,163.40	952.51	1,073.77	1,044.82	979.84
South Athens	1,137.75	926.22	1,043.20	1,001.87	920.06
Piraeus region	921.18	803.93	918.57	847.14	804.47
Riga	3,630.99	3,527.86	3,402.66	3,074.42	3,780.50
Região de Coimbra	971.12	1,231.76	1,042.54	940.34	947.21

Source: (Eurostat, 2023b)

Table 9. Cooling degree days in REVERTER pilots - annual data

	2017	2018	2019	2020	2021
Brezovo (based on Plovdiv NUTS3)	258.67	154.58	170.98	174.72	240.67
North Athens	502.67	453.33	482.38	481.47	567.14
West Athens	610.13	573.78	619.44	627.85	682.31
Central Athens	518.45	507.07	523.94	568.55	631.23
South Athens	526.70	525.78	539.97	596.25	651.90
Piraeus region	649.22	625.41	642.99	683.58	696.61
Riga	6.84	65.31	21.86	12.10	93.11
Região de Coimbra	138.86	152.90	87.40	120.51	60.87

Source: (Eurostat, 2023b)

3.1.2 Population characteristics

According to the lates Population Census (2021), the population of **Brezovo Municipality** is 6,170 people. The population decreased 1,128 people or 15.4% over the last decade. On of the main conclusions of the analysis of the population census by age is that the population is ageing, and the highest share of the population consists of people over 70 years old. The gross domestic product (GDP) per capita is lower than the national average (the GDP per capita in the Plovdiv district is BGN 14,460, while the national average is BGN 17,170). The unemployment rate in the district is lower than the national average (3.0%, against 5.2% nationwide). Nevertheless, 30% of the population are below the poverty line, exceeding the national average (around 23%).

With a population over 3,000,000, the **Athens Urban Area** is the largest urban conglomeration in Greece, with high population density. A worrisome finding of the last Population Census (2021) is that the population of the Attica Region, and consequently of the pilot area, is ageing. In line with this fact, the share of one-person households (34.8% in total) has increased by around 37% and that of two-person households (27.4% in total) by 4%, while three-person (18.7% in total), four-person (14.6% in total) and five or more-person (4.6% in total) households have decreased by 2.3%, 10.7% and 9.9%, respectively (Hellenic Statistical Authority, 2023). In absolute terms, the GDP of the Athens Urban Area was 65.95 billion € in 2020, accounting for about 40% of the whole Greek economic output. The GDP per capita was more than 21,500 € or 140% of the national average in the same year, and the unemployment rate stood at 14.2% (national unemployment rate: 16.3%). Significant income inequalities are also observed within the Athens Urban Area regions. Compared to Central Athens, which is the richest region in the study area, the GDP per capita in North Athens is around 82%, in South Athens and Piraeus about 59%, and in West Athens only 35%. The overall percentage of p population at risk of poverty is around 14%.

Since 1991, **Riga**, as most areas of Latvia, has seen a gradual decline in the number of inhabitants (i.e., the population has decreased by 32%). At the beginning of 2021, the population of Riga city reached 621,120 people. Riga is characterised by a multinational composition of the population; the city is mostly inhabited by residents of Latvians (47.2% in 2021) and Russians (36% in 2021). In 2020, the largest number of inhabitants is concentrated in the microdistricts of Soviet-era apartment buildings – Purvciems (55,024 inhabitants, 9%), Kengarags (45,783 inhabitants 7%) and Imanta (43,835 inhabitants 7%). The other neighbourhoods are below 4%. Riga's economy forms an important part of the country's economy, in terms of GDP, number of employees, number of enterprises, investment volumes, as well as other indicators. About 341,600 or 34.8% of the total economically active population of Latvia live in Riga, and a total of 480,100 people is employed in Riga, which is 46% of all employed in Latvia.

The **Coimbra Municipality** has around 135,000 inhabitants. Its population is considerably aged, with an ageing index of 203.9 against the Portuguese average of 157.4 and the EU27 average of 132.3. Being mostly a tertiary sector economy, with the main activities being related to hospitals, schools, universities, etc., the Coimbra population, on average, has a good level of education and reasonable purchase power, when compared to other cities or rural areas. In 2018, the Gini coefficient in the region was 4.7. In the Centro Region, the GDP per capita is 21,500 €, the unemployment rate is 6.3% and the share of the population at poverty risk is 15.6%.

3.1.3 Housing characteristics

In 2021, there were a total of 6,422 dwellings in **Brezovo Municipality**. Among the total dwellings, 2,679 (42%) were used for permanent or usual residence. Moreover, there were 2,315 (36%) dwellings designated for seasonal or vacation residence. The Census analysis indicates that there were 1,426 (2%) apartments unoccupied for reasons other than being a seasonal or vacation residence. This category may includes vacant properties for various reasons, such as being in the process of sale, renovation, or other non-residential purposes.

The majority of dwellings are private single houses with low levels of efficiency (>95%). The results from the National Census show that 74% of the dwellings in Brezovo have no renewed windows, and 91% of the dwellings are without insulation. According to the Municipal Energy Efficiency Programme, the residential sector of the municipality of Brezovo occupies the largest percentage of the municipality's final energy consumption – 59.4%, consuming a total of 26.6 GWh of energy. Looking at the percentage of energy sources used, the dominant use is the use of raw wood for domestic heating (47%), followed by the consumption of electricity (39%) and coal (12%). Heating is based mostly on the use of wood and coal and a minor share of electricity. The high levels of use of wood and coal are a prerequisite for influencing the air quality.

The latest Greek Housing Census was conducted from July to October 2021, but the results have not yet been released. Therefore, the description of housing characteristics in **Athens Urban Area** is based on the previous census, which was conducted in 2011, regarding the number of houses, the construction period and the size). For the energy performance characteristics of the buildings, however the statistical results of the Energy Performance of Buildings Certificates (EPBCs), which are presented annual and quarterly basis for the Hellenic Territory by the Ministry of Environment and Energy (https://bpes.ypeka.gr/?page_id=21&stat=222) were also used.

Based on the 2011 Greek Housing Census, the total number of residences is around 1,662,500. About 37.6% are located in Central Athens, 17.2% in North Athens, 14.2% in West Athens, 16.6% in South Athens, and 14.4% in Piraeus region. About 62% of the houses were built before the implementation of thermal requirements and energy-related building codes (before 1980). The area with the oldest houses is Central Athens (around 75% of the houses were built before 1981), followed by Piraeus region (about 62% of the houses were built before 1981). North Athens, on the other hand, shows the lowest percentage of old buildings (around 44.5%). West and South Athens lie in the middle, i.e., the pre- 1981 houses make up 58.6% and 54.6%, respectively. As far as the size is concerned, 12.4% of dwellings are less than 50 m^2, 39.3% between 50 and 79 m^2, 32.5% between 80 and 109 m^2, and the rest (i.e., 15.8%) more than 110 m^2.

According to the results of the 2011 Housing Census, 883,948 dwellings (53.2%) in the area of interest have some kind of insulation, while 778,561 dwellings (46.8%) have no insulation. According to the analysis of the EPBCs, which is based on more than 797,000 EPBCs issued in the period 2011-2021, about 62% of primary energy consumption is used for heating, 21.8% for domestic hot water (DHW), 16.2% for cooling and less than 0.01% for lighting. Moreover, only 0.02% of primary energy consumption is produced by RES. More than 71% of dwelling in the area of the Greek pilot are classified in the three worst energy classes (E, F and G), about 25% in the middle energy classes (C & D), and only 4% in the highest energy classes (A+ to B).

Of particular interest are the results of the energy upgrading of houses that participated in the programmes “Exoikonomo I and II”, “Exoikonomo – Autonomo” and “Exoikonomo 2021”. In these dwellings, it is observed that the largest percentage, after the energy interventions, is classified in energy categories C, D and E. From the year 2021, the energy interventions lead to dwellings in energy categories B to A+ (Hellenic Ministry of Environment and Energy, 2022). It is worth noting the energy saving potential of the three lowest energy classes (E, F and G), which ranges from 21%

(when houses are upgraded by a maximum of one energy class) to around 96% (when they are upgraded to the highest energy class).

In the **City of Riga**, there are in total 11.7 thousand three- or more apartment buildings (about 29.7% of the total number of apartment buildings in Latvia). Referring to the data provided by the REA, the total useful area of apartment buildings in Riga is 18,615 thousand m^2, where the average useful area is 1,585 m^2 per building.

Apartment buildings and their quarters are located in different areas of the city of Riga. Based on the years of construction of apartment buildings, which also affect their energy performance requirements, they can be divided into the following groups:

i. Pre-war buildings built until 1945. They are basically located in the Riga City Centre District and the Old Town.

ii. Buildings built during soviet occupation (USSR) built between 1946 and 1991, which are mainly located in the peripheral districts of the city of Riga (e.g., Bolderāja, Imanta, Mežciems, Pļavnieki, Purvciems, Ziepniekkalns, Zolitūde, etc.). They account for the largest share of apartment buildings in Riga both in number and area.

iii. New buildings built after 1992, which are located in different districts of the city of Riga and are in relatively small numbers.

The largest share of buildings (59%) are buildings that were put into operation in the period up to 1945. Buildings put into operation in the period from 1946 to 1993 have the largest useful area (56% of the total), that is, buildings built during the USSR. Studies show that the energy efficiency requirements of multi-apartment buildings built during the USSR occupation and up to 2015 do not comply with the requirements of the currently valid Cabinet Regulation No. 280 “Regulations Regarding the Latvian Construction Standard LBN 002-19 "Thermal Engineering of Building Envelopes”. As a result, Riga has a high share of buildings in need of deep renovation (about 6,000 apartment buildings) and at the same time low activity of renovation of existing buildings. By 2019, only 159 or 1.4% of the total number of apartment buildings in the city of Riga have been renovated in Riga.

Residential buildings represent the vast majority of the building stock in Portugal (Monzón-Chavarrías et al., 2021). The building characteristics of **Coimbra region** are influenced by its historical and cultural heritage, as well as its geographical and climatic conditions. Coimbra has a variety of architectural styles, ranging from Romanesque, Gothic, Renaissance, Baroque, to Modernist. The traditional buildings in Coimbra are mostly made of stone, brick, and timber, with tiled roofs and plastered walls. In the old city, the buildings are usually arranged along narrow streets and alleys, forming dense urban blocks and are, in general, in bad condition. Some of the common building features are balconies, arcades, courtyards, and decorative elements such as azulejos (painted ceramic tiles), stucco, and wrought iron. The city has grown in the decades 60´s-90´s with a boom of new constructions, mainly buildings with more than 4 floors and new districts have been set in the city. The decades 1961–1980 are typically considered as a period with buildings with a poor energy performance. For example, some experts studied the constructive solutions and energy performance of Portuguese buildings and argue that buildings erected during the 60’s, 70’s and 80’s are the ones with the highest energy saving potential (Sousa et al., 2013). Other experts studied the energy performance certificates of residential buildings in Portugal and found that buildings erected before 1980 have higher levels of nominal heating energy needs (Magalhães & Leal, 2014). The quality of residential buildings in the Coimbra region is affected by several factors, such as the design, materials, construction, maintenance, and performance of the buildings. According to a study, the majority of the traditional buildings in Coimbra have a high seismic vulnerability due to their poor structural condition and lack of adequate seismic capacity (Vicente et al., 2006).

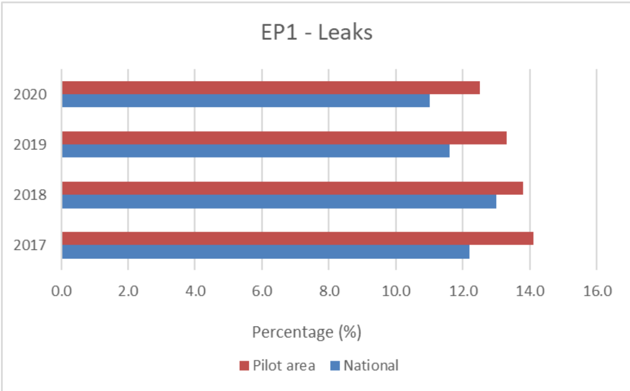
The Coimbra Municipal Housing Park (social housing) consists of a total of 854 dwellings, with different typologies, integrating building apartments and houses dispersed over the city. The buildings were built before the first building code entered into force in 1990, and therefore those buildings do not have any thermal insulation. Part of the social housing park in the city centre has recently undergone some retrofits, but the actions taken were mainly on painting the façades. Hence, the existing potential for energy renovations is high. Moreover, a large share of inhabitants is elderly and low educated, who cannot afford to carry out improvements and construction works or do not have the knowledge on how to start the renovation journey, and therefore a holistic approach is required to have a high impact. Sound impartial advice on what is best for improving the overall environment and actions geared towards behavioural changes and capacity building can lead to significant improvements in households' well-being.

3.2 Energy poverty

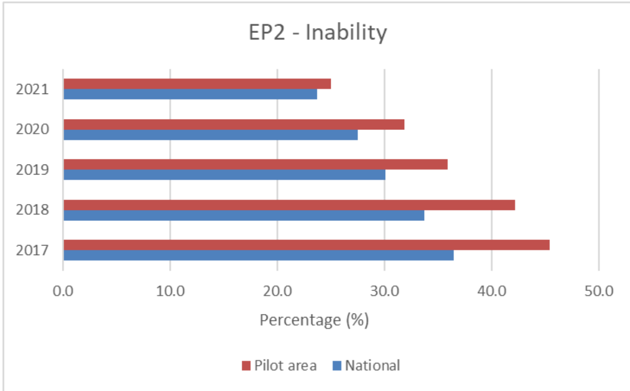
As mentioned in Section 2, the energy vulnerability analysis was based on data from Eurostat's EU SILC survey for all Pilots and from HBS survey for the Brezovo and the Athens Urban Area Pilots, employing a number of different indicators (see Section 2 for details). A more detailed analysis is provided in Annex I, while this section summarises the main findings.

3.2.1 Energy poverty in the Brezovo Pilot

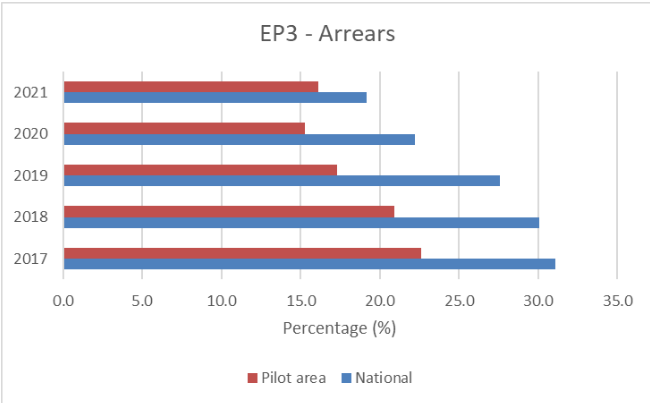
Figure 1 presents the main consensual EP indicators for the Brezovo Pilot. The share of population living in a dwelling with leaks, damp or rot in the area of the Bulgarian pilot is higher than the national share (almost by 1-2%). The same is true for the share of population not able to keep home adequately war. However, the difference decreases over the years (i.e., from 8.9% in 2017 to 1.5% in 2021). In contrast, the share of population having arrears on utility bills is lower in the pilot area compared to the national indicator. Again, the difference decreases over the years (i.e., from 10.3% in 2019 to 3.1% in 2021). In general, it appears that the consensual EP indicators in the pilot area are approaching the corresponding national indicators over time and, as is the case nationally, are improving.



(a)



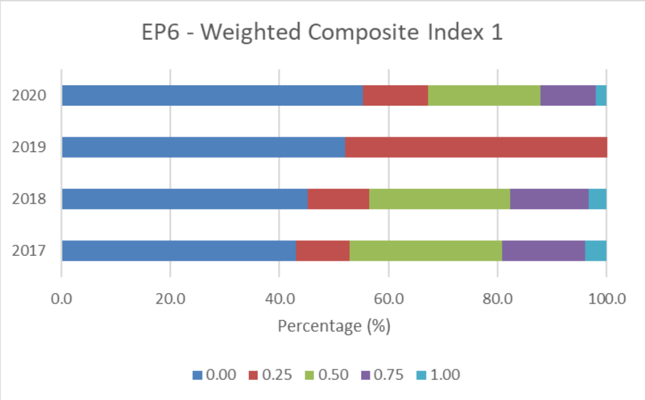
(b)

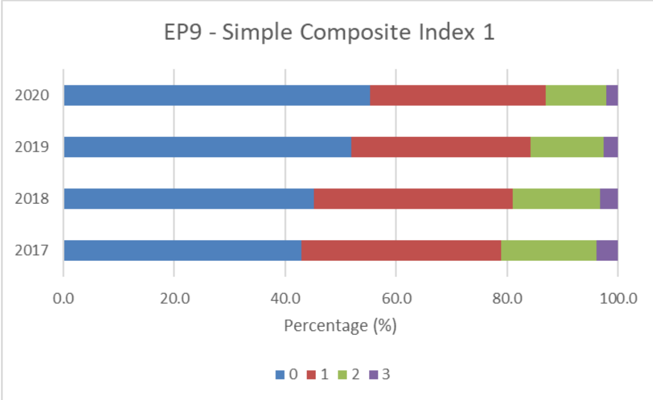


(c)

Figure 1. Consensual EP indicators in Brezovo pilot – (a) Share of total population living in a dwelling with leaks; (b) Share of population not able to keep home adequately warm; (c) Share of population having arrears on utility bills in the past 12 months

The reduction in the intensity of the problem is also reflected in the results of the Weighted (WCI) and Simple (SCI) Composite Indices. As shown in Figure 2**Error! Reference source not found.**, the percentage of the population not experiencing EP issues increased from 43% in 2017 to 55.3% in 2020. More importantly, the percentage of those experiencing severe EP issues has been reduced by around 50%, from about 4% to 2%.





(a) (b)

Figure 2. Selected composite EP consensual indices in Brezovo pilot – (a) Share of population at EP according to WCI1; (b) Share of population at EP according to SCI1

Finally, the proportion of the population in the pilot area that experiences any type of EP, i.e., arrears on utility bills, leaks or inability to keep their house warm, presents also a decreasing trend (Figure 3). It may be redundant, but it should be noted that the percentage of EP households is significantly high based on this indicator, as practically all individual energy poverty indicators are added together.

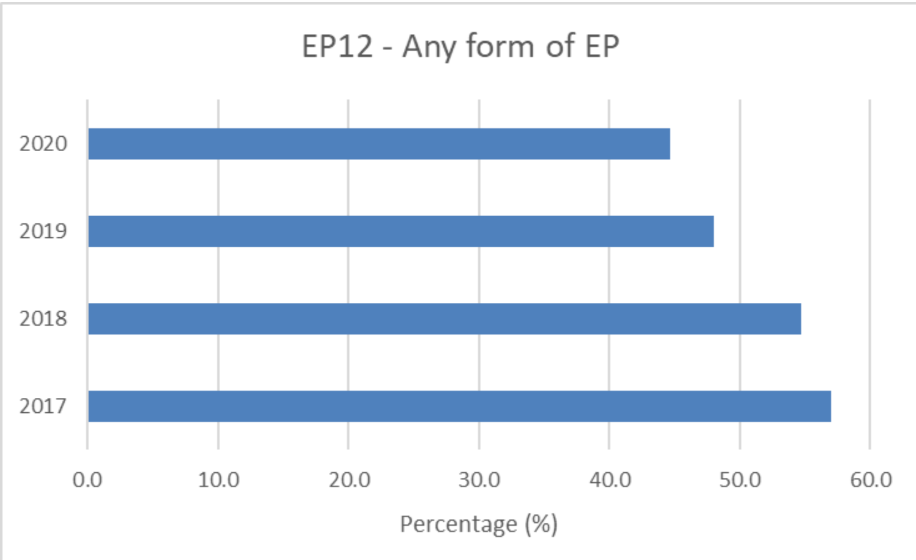
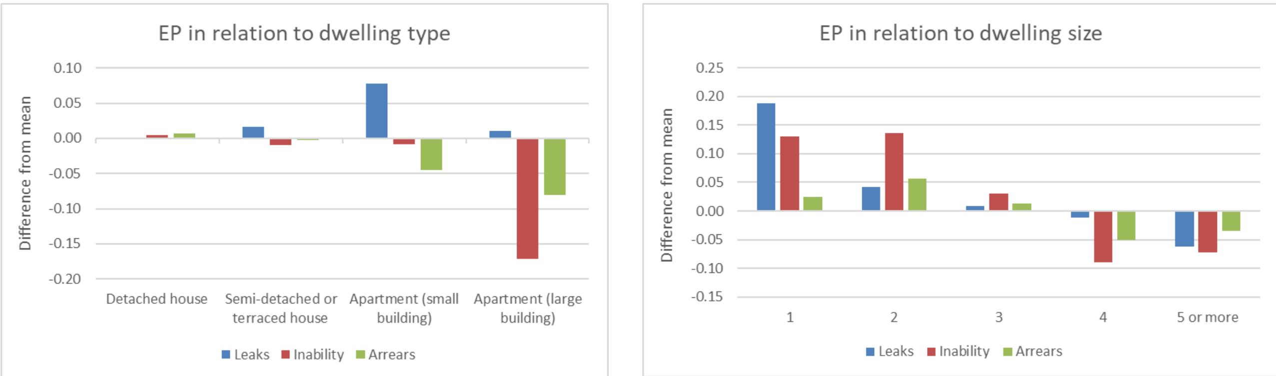


Figure 3. Share of population at EP according to EP12 in Brezovo pilot

To explore how certain housing characteristics and households' living conditions are related to EP vulnerability, the difference in EP rates of the investigated indicators relative to their average rate in the pilot area was examined. As illustrated in Figure 4, households living in large buildings are less prone to arrears and more capable to keep their apartments adequately warm compared to those living in small buildings, detached or semi-detached houses most probably because they have, on average, higher income. The size of the house is also associated with the three basic EP indicators. Those living in one- or two-room houses have higher EP rates compared to the average, while those living in houses with four or more rooms have lower EP rates. The most likely explanation for this result is the difference in income. For example, the average income of the households that live in one- or two-room houses ranges between 3,200-4,200 EUR, while the average income of the households living in houses with more than four rooms is more than 9,500 EUR, on average.

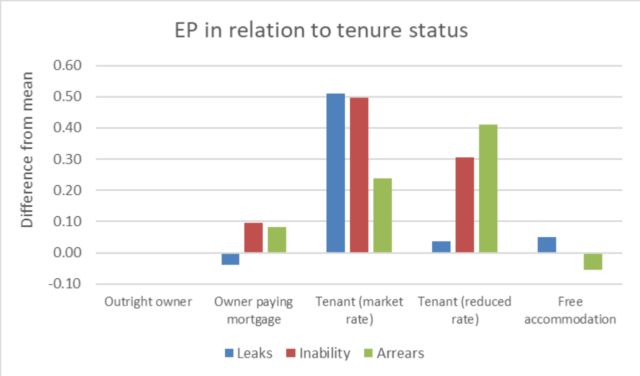


(a) (b)

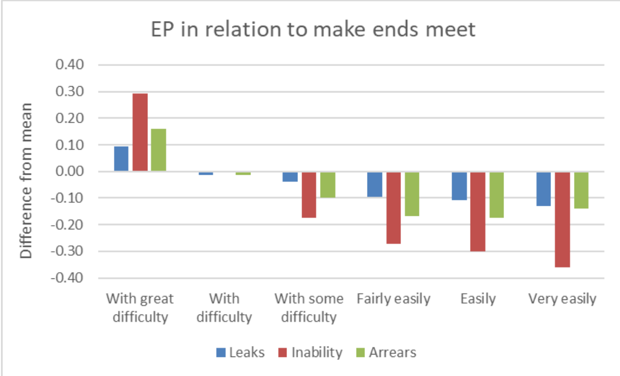
Figure 4. Leaks, inability to keep house warm and arrears on utility bills in relation to dwelling type (a) and in relation to dwelling size (b) in Brezovo pilot

The role of tenure status and income in EP is illustrated evident in Figure 5. As far as tenure status is concerned, the most vulnerable groups to EP are tenants who pay rent (either at market or at reduced rate). These results should however be viewed with caution because the number of observations in these categories is very small (less than 15). Households experiencing great difficulty in making ends meet have differences in EP rates of up to 30% compared to the average rates. On the contrary, those who can pay easily for their usual necessary expenses have quite lower EP rates (e.g., differences from the average of more than 30% in the ability to keep their houses warm).

The above-mentioned patterns are observed, and are even more pronounced, in the complementary EP indicators.



(a)

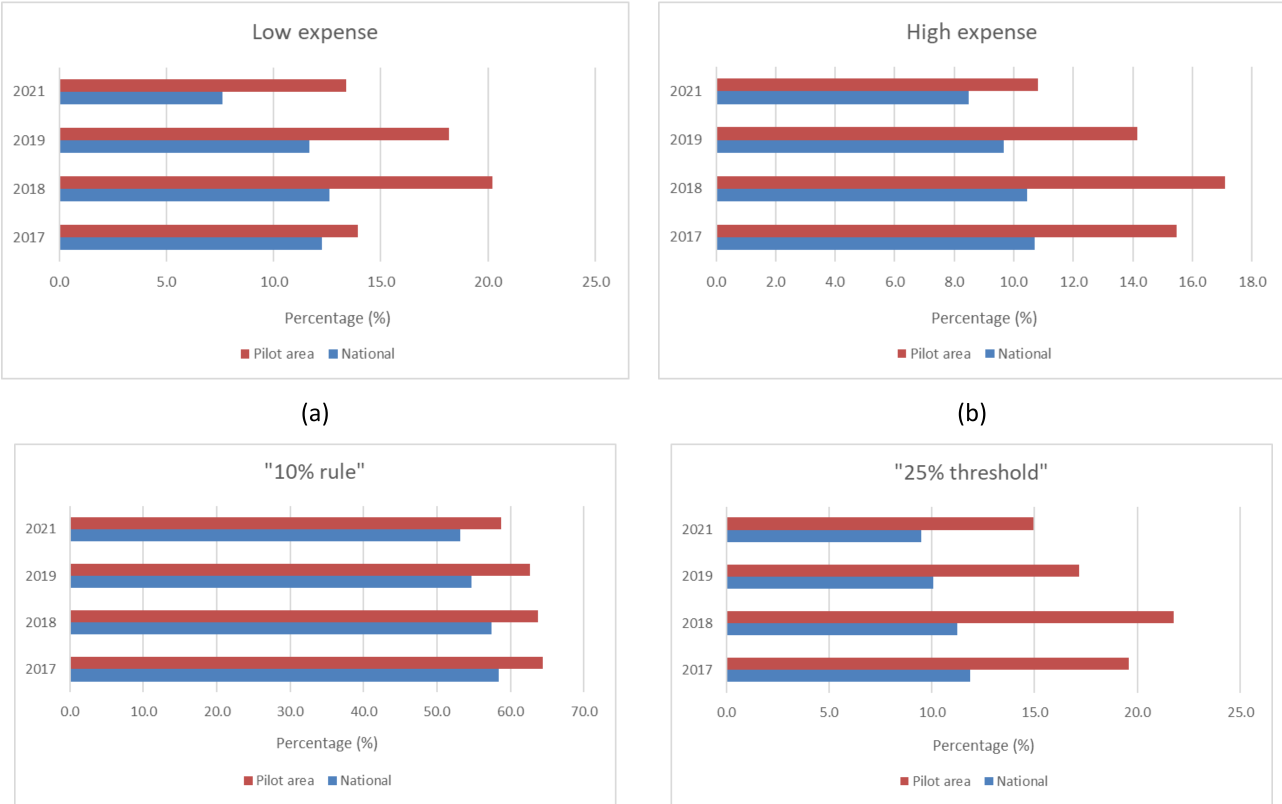


(b)

Figure 5. Leaks, inability to keep house warm and arrears on utility bills in relation to tenure status (a) and the level of difficulty in making ends meet (b) in Brezovo pilot

As mentioned in Section 2, four EP expenditure-based indicators were formed and calculated in the case of Brezovo from the HBS dataset. Based on Figure 6, the following remarks can be made:

- After an increase in 2018, all EP expenditure indicators decline steadily. The same pattern is observed in the consensual-based EU SILC indicators.
- According to the Low Expense, High Expense and "25% threshold" indicators, the share of population facing EP problems is around 15%, on average. The "10% rule" seems to overestimate the EP problem (more than half of the population is characterised as EP).
- The EP levels in the area of interest, i.e., the Brezovo pilot, are higher than the national averages for all four indicators by around 11% (for the "10% rule" indicator) to more than 75% (for the Low Expense indicator).
- The gap between the pilot area and the national average is gradually narrowing for three indicators, i.e., "10% rule", High Expense and "25% threshold". Nevertheless, the gap increases for the Low Expense indicator, i.e., from 55.6% in 2019 to 76.2% in 2021.



(c) (d)

Figure 6. Expenditure-based indicators calculated in Brezovo pilot – (a) Share of population whose absolute level of energy expenditures is less than half the national median; (b) Share of population whose energy expenditure-to-income ratio is more than twice the national median. (c) Share of population whose absolute level of energy expenditure is more than 10% of their income; (d) Share of population whose energy expenditure exceeds 25% of total expenditures

To explore the role of income, ten different income classes were created using the median national income per year. Because in some income classes the number of observations was relatively low, the ten income classes were grouped into three income categories, i.e., low-income households (Income classes 1 to 3, i.e., those who have income below 60% of the national median income); middle-income households (Income classes 4 to 7, i.e., those who have income between 60% and 140% of the national median income); and high-income households (i.e., those who have income over 140% of the national median income).

As shown in Figure 7, there is an unquestionable correlation between EP and income for all indicators. For example, the share of the population experiencing EP issues based on Low Expense indicator is more than three times higher in the low-income class compared to the middle-income class, and 5.5 times higher compared to the high-income class. Similar conclusions can be drawn from the other HBS EP indicators. Taking into account that, as a rule, low-income households live in low energy-efficient houses and, in addition, these households are unable to retrofit their houses for financial reasons, it exacerbates the problem and traps them in a vicious cycle.

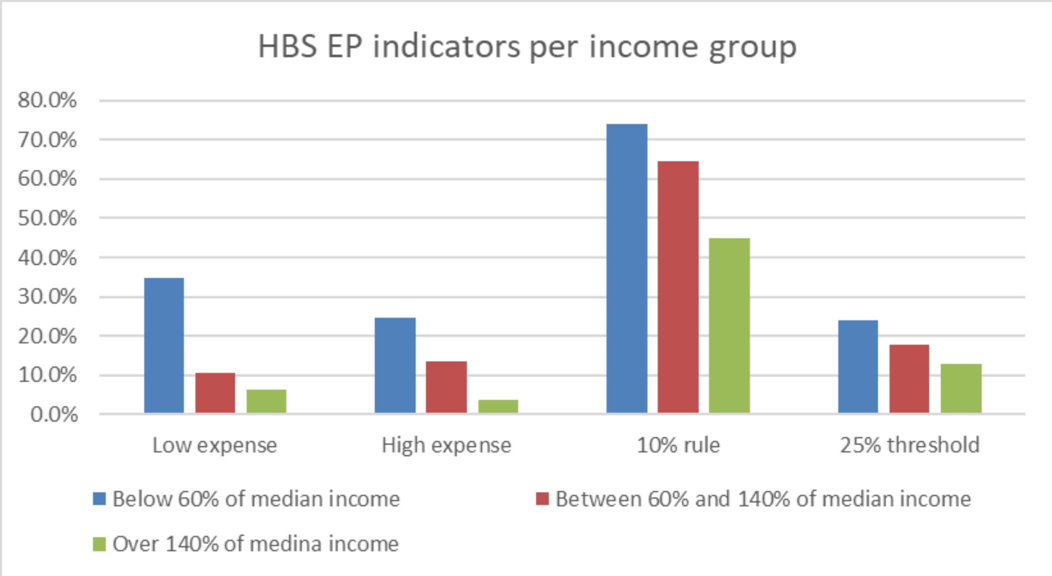


Figure 7. HPS expenditure-based EP indicators per income group in Brezovo pilot

3.2.2 Energy poverty in the Athens Urban Area Pilot

As regards the main EU SILC indicators (Figure 8), the share of population living in a dwelling with a leaking roof, damp walls/floors/foundation within the Greek pilot is lower than the national share (by 1.3%), as also has been the case since 2017, without significant differences over the years. The share of population not being able to keep their home adequately warm is slightly lower than the national level (by 0.8%). Similar conclusions are drawn for the share of population having arrears on utility bills, which is also lower than the respective national share (by 5.1%), and follows the same trend since 2017, with both the rates of the pilot-area level and the national level decreasing over time. The differences between the shares of the pilot area and the national level do not follow a consistent pattern, yet both the EP rates of the pilot area and the national level are decreasing over time.

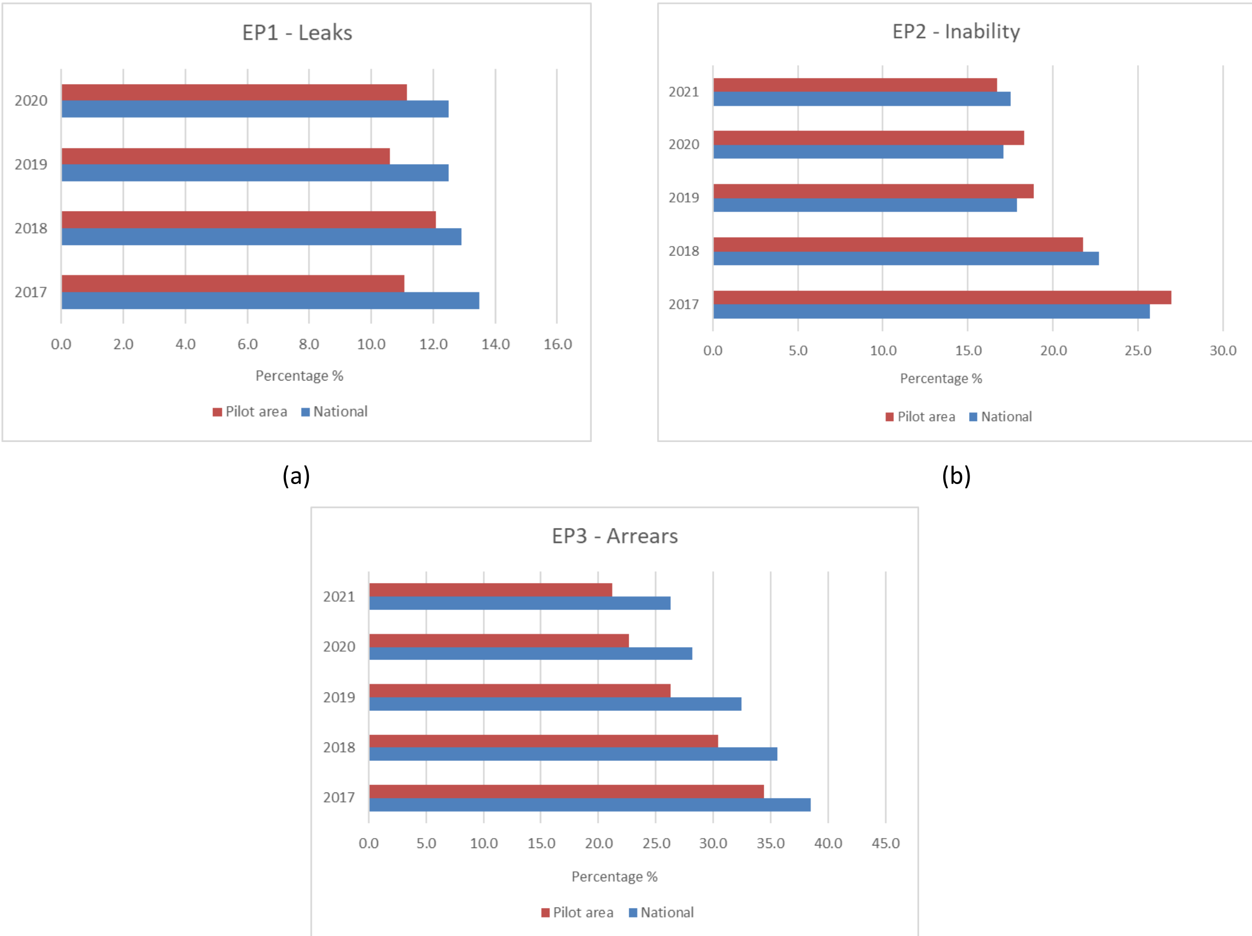
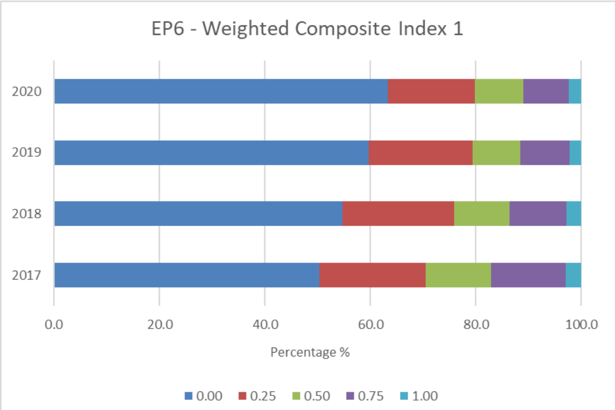
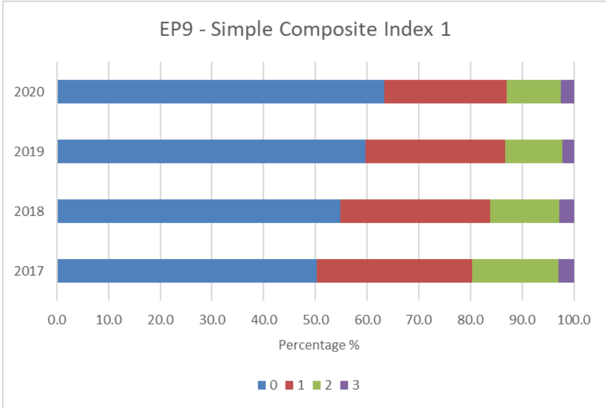


Figure 8. Consensual EP indicators in Athens Urban Area pilot – (a) Share of total population living in a dwelling with leaks; (b) Share of population not able to keep home adequately warm; (c) Share of population having arrears on utility bills in the past 12 months

The relative improvement in terms of EP issues is also apparent in the results of the Weighted (WCI) and Simple (SCI) Composite Indices. According to **Error! Reference source not found.**, the share of population not experiencing EP issues increased from 50.3% in 2017 to 63.3% in 2020, whereas the share of those experiencing severe EP issues (i.e., the WCI1 equals to 1) dropped by just 0.5%.



(a)



(b)

Figure 9. Selected composite EP consensual indices in Athens Urban Area pilot – (a) Share of population at EP according to WCI1; (b) Share of population at EP according to SCI1

The percentage of population experiencing any type of EP, i.e., arrears on utility bills, inability to keep their house adequately warm, or leaks/damp walls, has been constantly decreasing since 2017 (Figure 10). More precisely, a reduction of 26% was marked between 2017 and 2020. This kind of indicator presents high rates, as practically combining all single EP indicators.

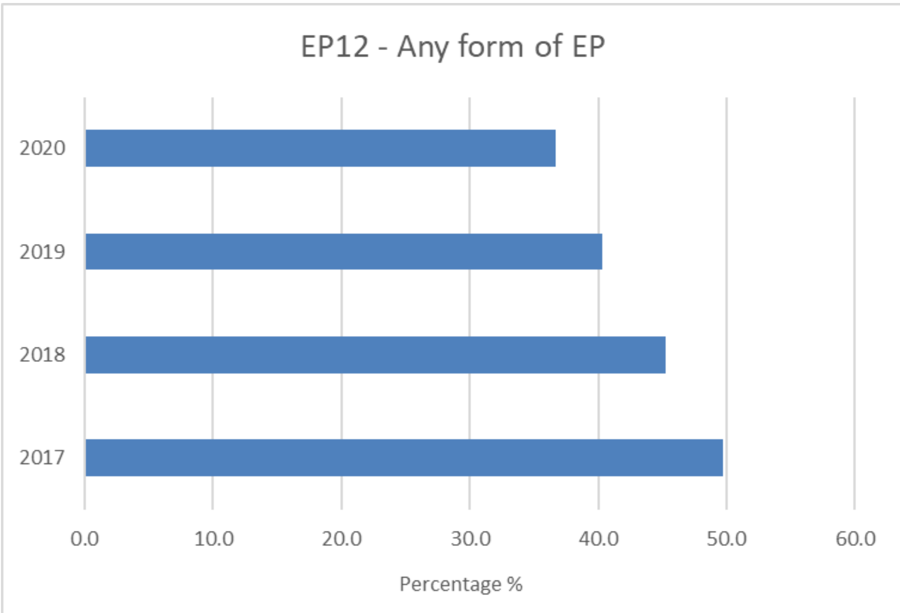
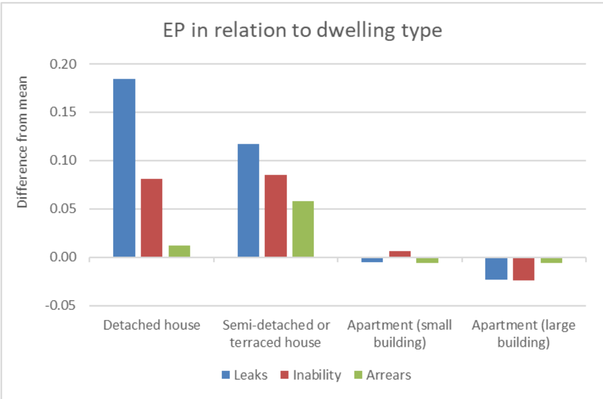
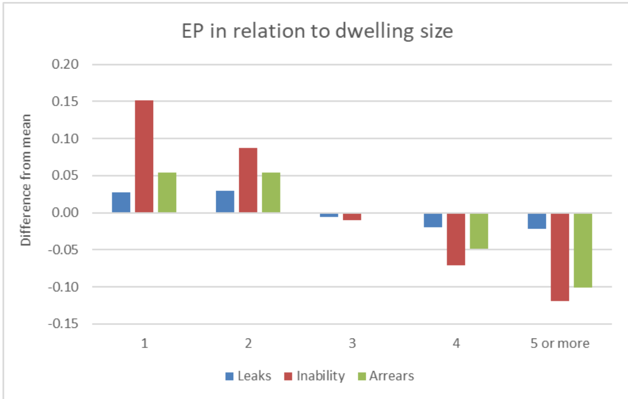


Figure 10. Share of population at EP according to EP12 in Athens Urban Area pilot

The consensual EP indicators were investigated with respect to certain housing features and living conditions to explore the effect of the last ones on EP vulnerability in the pilot area. As shown in Figure 11, households living in detached and semi-detached or terraced houses are more prone to almost all EP indicators (arrears, leaks, inability to keep home warm), with a focus on the problem of leaks, probably due to the more indoor-outdoor spaces and open-to-air walls of these buildings, which makes it difficult to heat sufficiently a building. Furthermore, households living in one- or two-room houses present higher EP rates compared to the average, i.e., there appear mainly problems with leaks, followed by arrears and inability to keep home warm, while households living in houses with four or more rooms have lower EP rates.



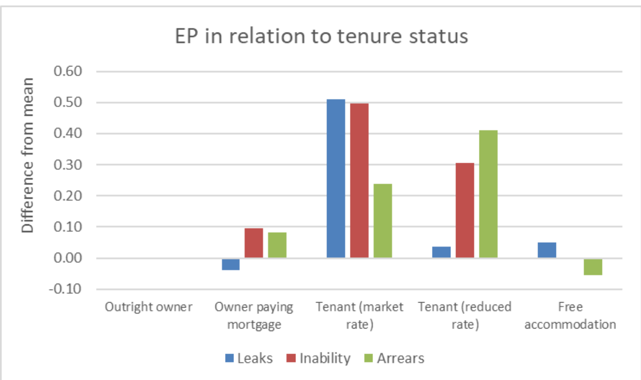


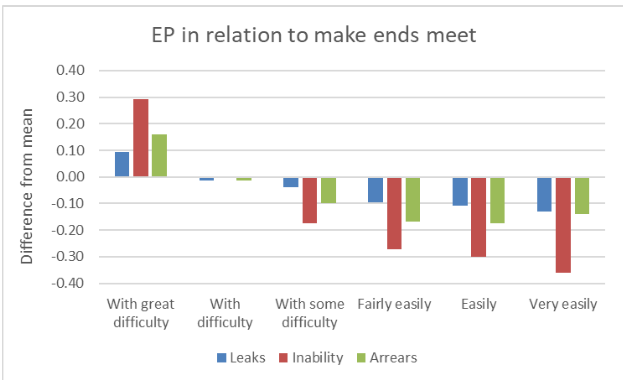
(a) (b)

Figure 11. Leaks, inability to keep house warm and arrears on utility bills in relation to dwelling type (a) and in relation to dwelling size (b) in Athens Urban Area pilot

As shown in Figure 12, the most vulnerable groups to EP are tenants (mainly those at reduced rate, followed by those at market rate) and households experiencing great difficulty in making ends meet face also higher EP issues, with differences in EP rates of up to 21% compared to average rates. On the other hand, households that can easily make ends meet present quite lower EP rates, of up to 29% versus average rates.

The above-mentioned patterns are observed, and are even more pronounced, in the complementary EP indicators.





(a) (b)

Figure 12. Leaks, inability to keep house warm and arrears on utility bills in relation to tenure status (a) and the level of difficulty in making ends meet (b) in Athens Urban Area pilot

The expenditure-based indicators, which were calculated for the Greek pilot based on the HBS data, are presented in Figure 13.

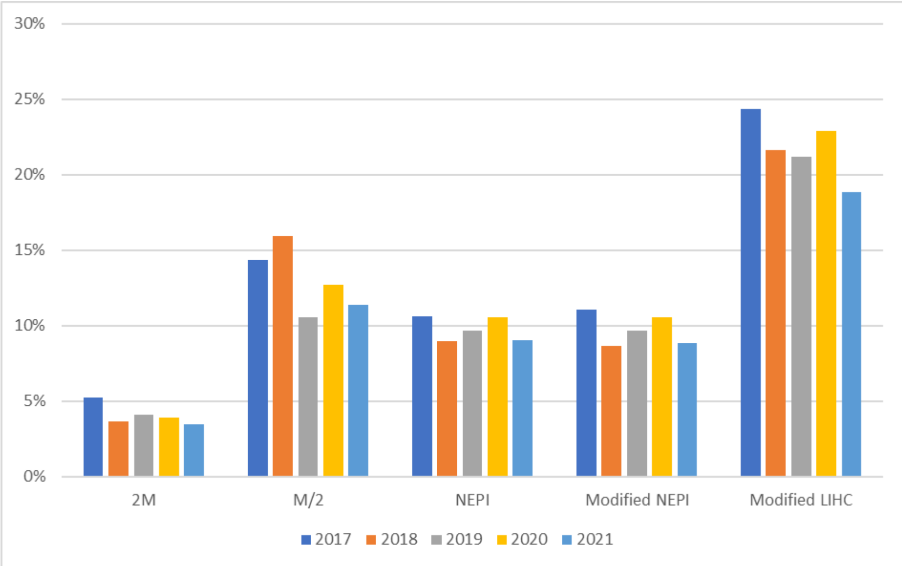


Figure 13. EP levels in in Athens Urban Area pilot based on five different expenditure indicators for the period 2017-2021

Considering the **2M index**, the estimated levels of EP are very low (3-5%), which is largely attributed to the fact that the index does not count as energy poor households that under-consume energy, a situation quite common in Greece during the last decade, due to shrinking incomes and high energy prices. With the **M/2 index**, energy poverty levels were calculated between 11% and 16% in the period 2017-2021. Nevertheless, this index shows also significant weaknesses as it may classify as EP, households whose energy costs are low because they live in homes with high energy efficiency, while at the same time does not consider as EP, households with high energy expenditures, though necessary to ensure adequate internal thermal conditions in the dwellings. Based on the national index (**NEPI**), the levels of EP were estimated at levels of 9-11% in the reference period and based on the two new energy poverty indicators they were found to range from 9-11% with the **modified NEPI** index and between 22-26% with the **modified LIHC**.

All the aforementioned EP indicators take into account various aspects of the problem, by integrating individual conditions and adopting specific thresholds in order to characterize a household as energy poor. Changing these thresholds, the estimated levels of energy poverty in a region may be significantly influenced. For example, both the NEPI and the modified NEPI require that a household's equivalised annual net income be less than 60% of the median equivalised income of all households, according to the national definition of relative poverty. In other words, according to these indicators, a prerequisite for a household to be energy poor is to be classified below the official poverty levels. Figure 14 shows indicatively how EP levels change, by altering the thresholds of the corresponding conditions. For example, by using increasing the levelised income threshold to 80% of the median of the corresponding income for all households, which essentially indicates that households above the poverty level may also suffer from energy poverty, the EP rates in the area of interest almost double at 18-20% for the reporting period.

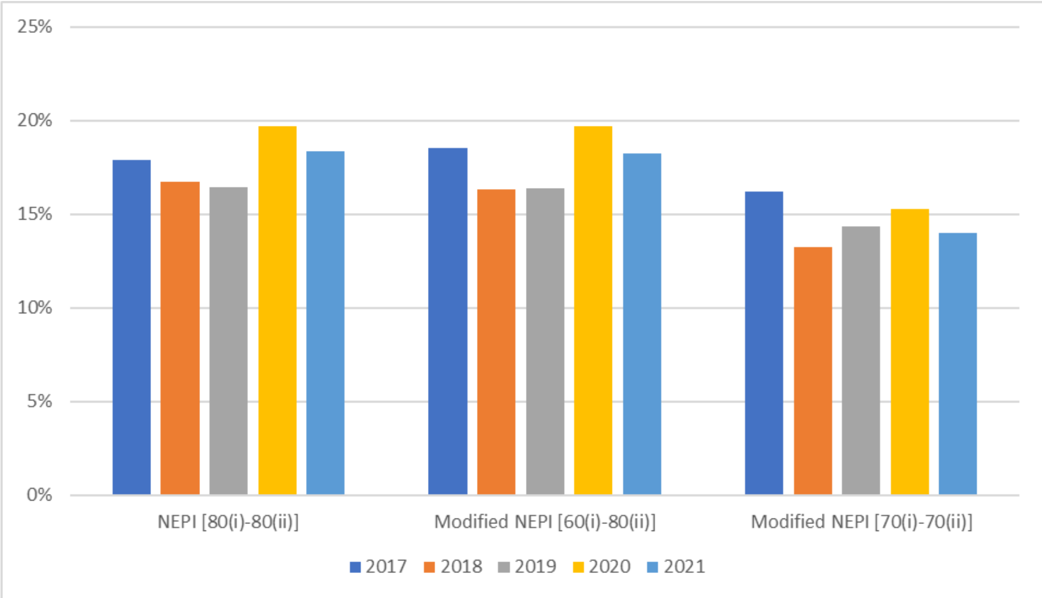


Figure 14. Estimated EP levels in Athens Urban Area pilot based on NEPI and modified NEPI indices, adopting different thresholds for the two conditions used to structure the index. Condition (i): the threshold of the real in relation to theoretical energy expenditures. Condition (ii): the threshold of the levelised income in relation to national median.

For all five expenditure-based EP indicators, it is examined how certain housing characteristics and living conditions of households influence the estimated levels of energy poverty.

As can be seen in Figure 15, EP levels are lower in households that live in apartments compared to those that live in detached or semi-detached houses. This is probably attributed to the fact that apartments generally have lower energy losses than single-family houses, and thus they require relatively lower expenditures to ensure adequate thermal comfort conditions. This is also consistent with the results of EPBCs in Greece. In addition, all indicators examined show that EP levels are lower in small apartment buildings. This probably has to do with the fact that the residents of relatively small multi-family buildings can more easily communicate with each other and agree to operate the central heating system that these buildings usually have. On the contrary, such an agreement is more difficult to achieve in large buildings with many occupants, which leads every household to look for alternative and usually inefficient ways of heating.

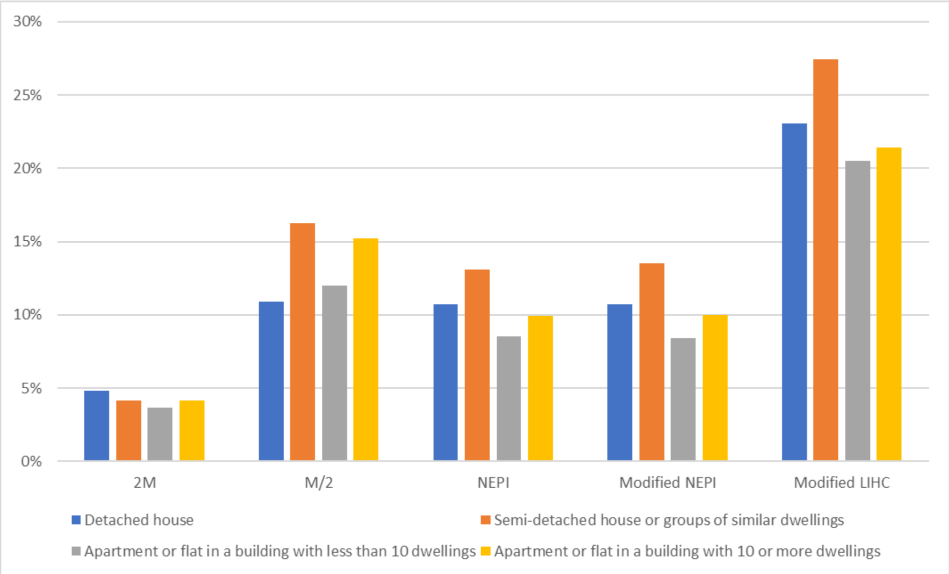


Figure 15. Estimated EP levels in Athens Urban Area pilot using the expenditure indicators in relation to dwelling type

As expected, households that pay rent for their housing show higher levels of EP than households that live in owner-occupied housing according to all EP indicators considered (Figure 16). It is also noteworthy that according to both NEPI and modified NEPI indices, the highest levels of EP occur in households, in which accommodation is provided for free by family or third parties. These are probably young families, at the beginning of their working life, with low incomes and perhaps high levels of unemployment, who consume less energy than required due to lower income.

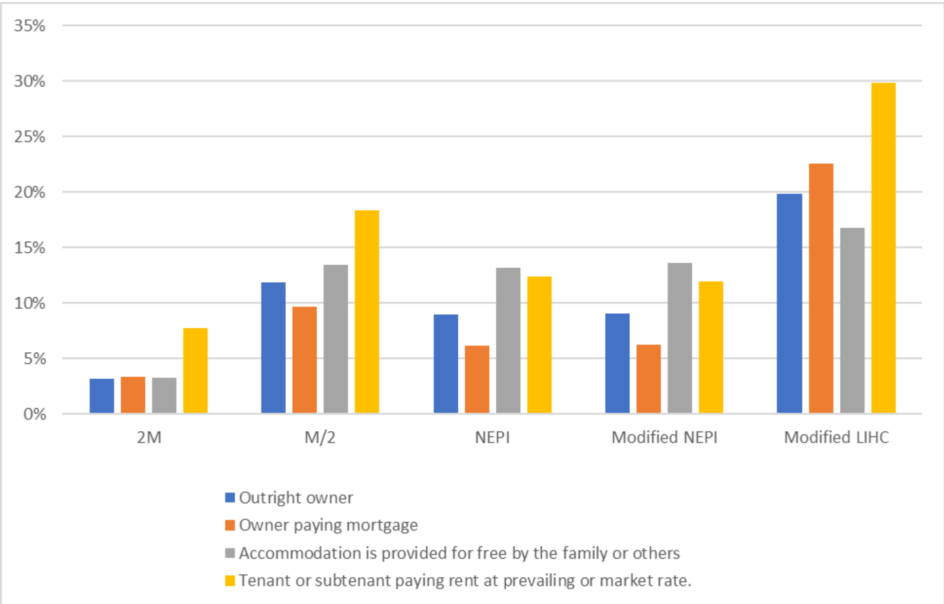


Figure 16. Estimated EP levels in Athens Urban Area pilot using the expenditure indicators in relation to tenure status

As a general trend, EP levels are higher in households living in small houses with a relatively small number of rooms (Figure 17). This is probably attributed to the fact that low-income households usually live in small-sized houses with a limited number of rooms. However, two of the examined indicators show an increase in EP levels in households living in residences with many rooms, demonstrating the high energy costs required to ensure adequate thermal comfort conditions in these dwellings.

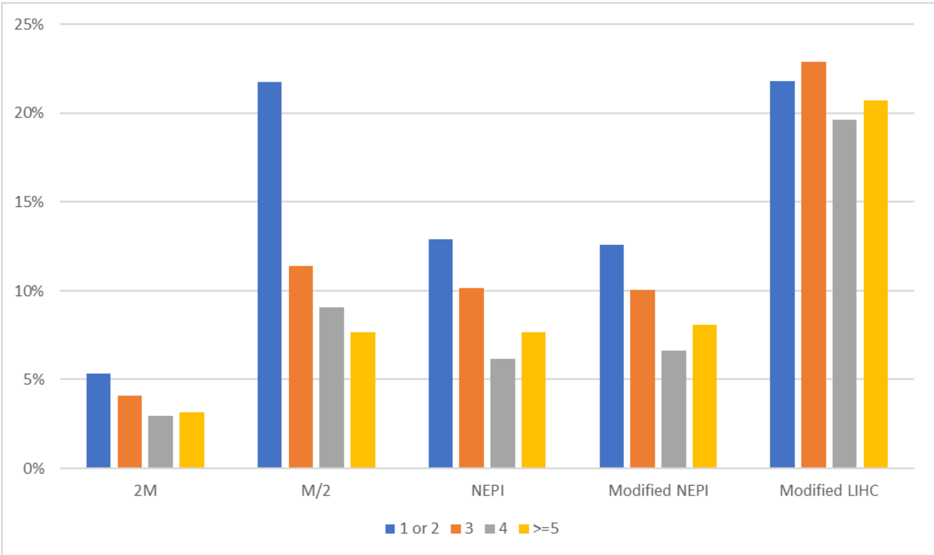


Figure 17. Estimated EP levels in Athens Urban Area pilot using the expenditure indicators in relation to the size of the dwellings

Figure 18 clearly shows that EP is directly linked to the year of construction of the households' residence and therefore to their energy performance. Specifically, based on all indicators examined (except 2M) the EP levels are significantly reduced in households living in dwellings built after 1980, when the first national Thermal Insulation Regulation came into force. As regards the EP levels of households living in houses built after 1980, they are affected both by the continued improvements in the energy performance of buildings as well as by the increases in the surface area of new homes. In any case, improving the energy efficiency of the building stock is a basic condition for structurally addressing the problem of energy poverty. Finally, as clearly depicted in Figure 19, the problem of EP is affected to a large extent by households' income. Specifically, the NEPI as well as the modified NEPI and the modified LIHC indicators clearly show that more than 2/3 of households belonging to the lowest income categories are characterized as energy poor.

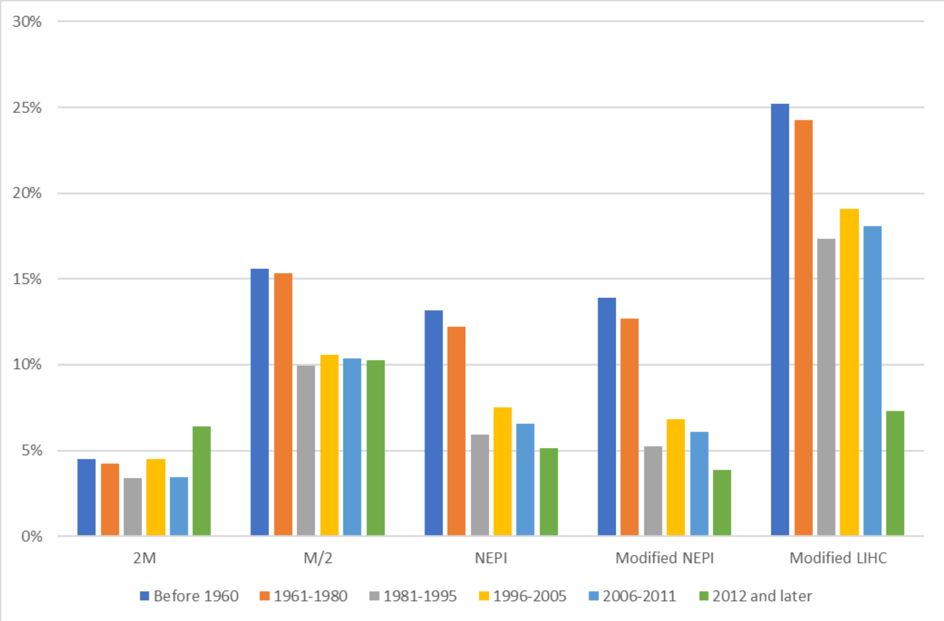


Figure 18. Estimated EP levels in Athens Urban Area pilot using the expenditure indicators in relation to the construction year of the dwelling

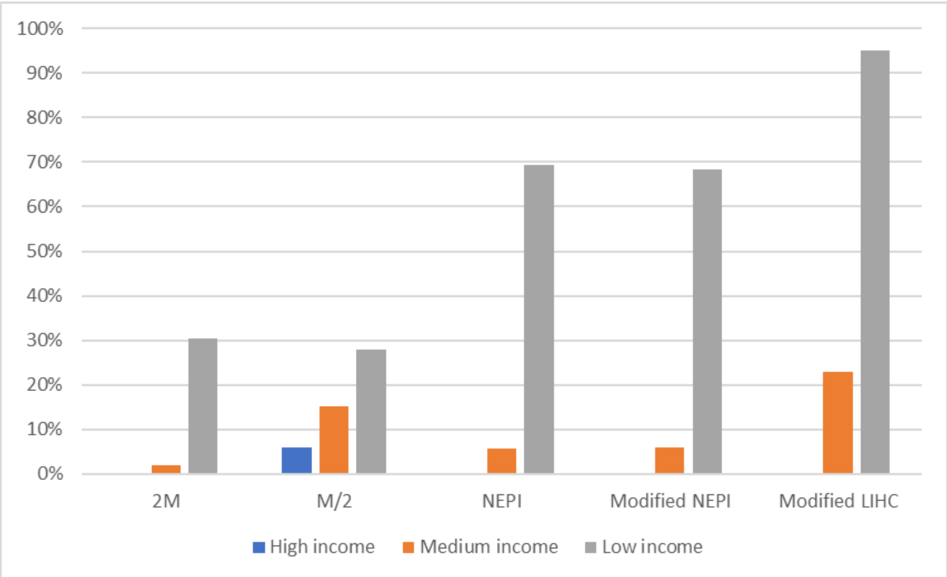


Figure 19. Estimated EP levels in Athens Urban Area pilot using the expenditure indicators in relation to income class of the households

3.2.3 Energy poverty in the Riga Pilot

According to Figure 20, the share of population living in a dwelling with a leaking roof, damp walls/floors/foundation within the Latvian pilot area is lower than the national share by nearly 3.5-6%. Similarly, the share of population with arrears on utility bills is lower in the pilot area than at country level, with the difference decreasing over time, from 2.5% in 2017 to 1% in 2021.

Conversely, the share of population not being able to keep home adequately warm is higher in the pilot area compared to the national average, with the discrepancy gradually decreasing from 6.8% in 2017 to 2.5% in 2021. In general, it appears that the consensual EP indicators are improving so much in the pilot area as nationally, while also the discrepancy between the two levels is significantly smaller over the years.

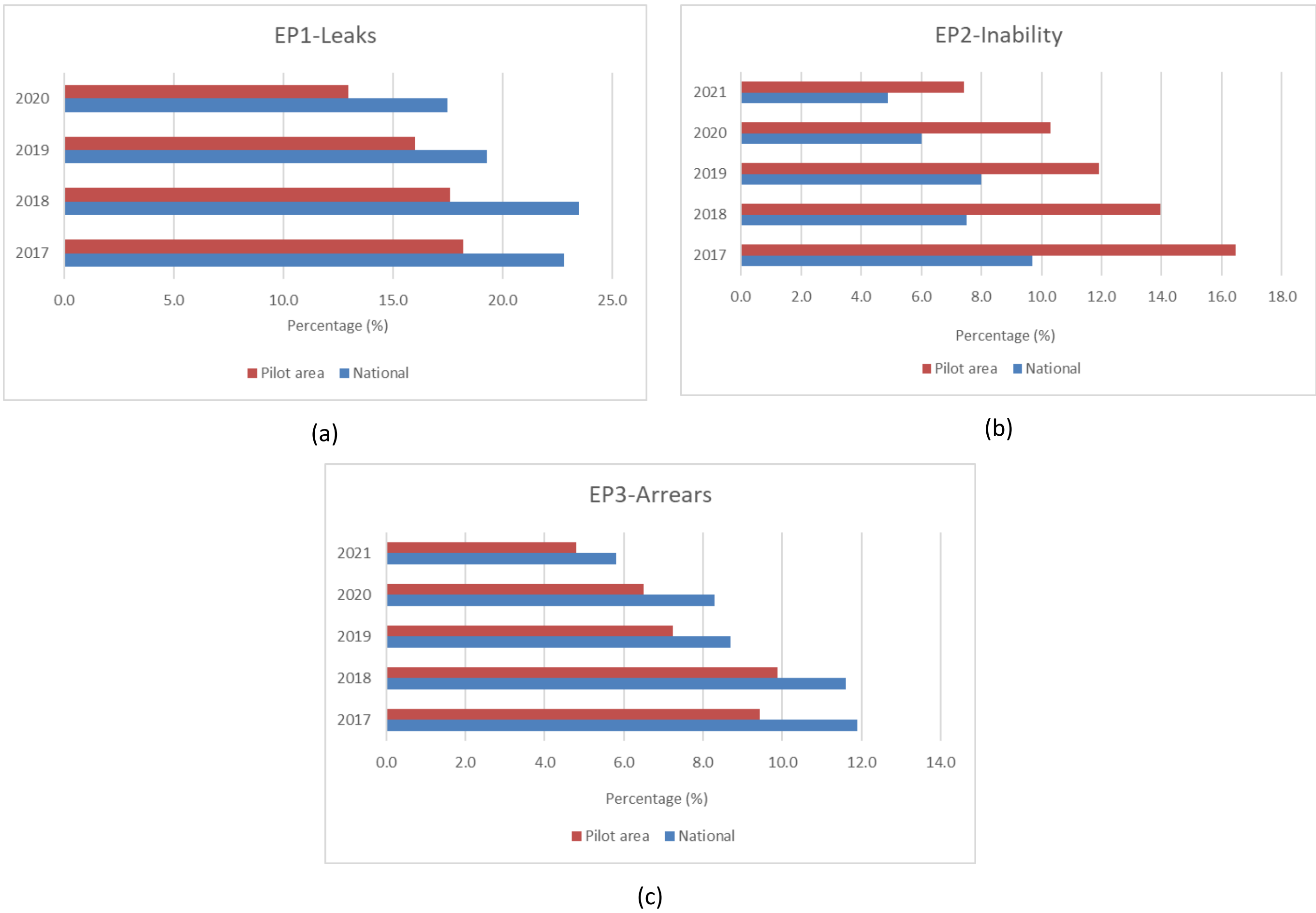
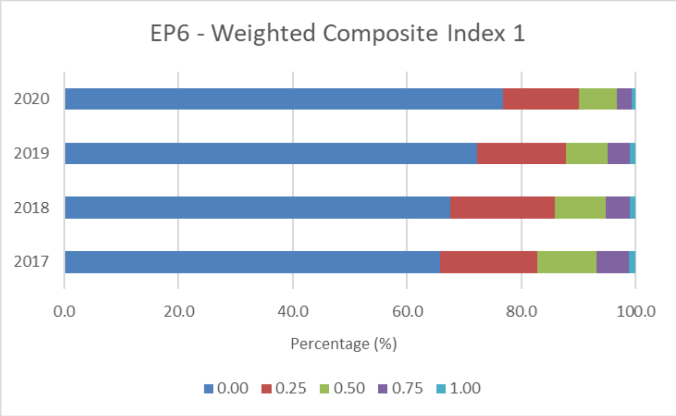
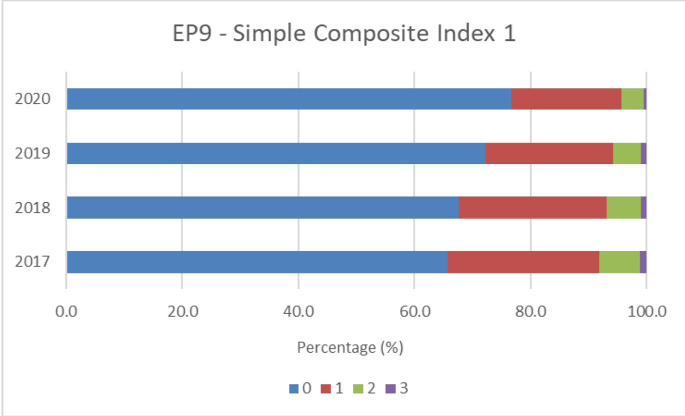


Figure 20. Consensual EP indicators in Riga pilot – (a) Share of total population living in a dwelling with leaks; (b) Share of population not able to keep home adequately warm; (c) Share of population having arrears on utility bills in the past 12 months

The results of the Weighted (WCI) and Simple (SCI) Composite Indices reflect the better condition of the energy poverty problem over the years. Indicatively, as regards the WCI1 (Figure 21), the share of population not experiencing EP issues increased from 65.8% in 2017, to 76.7% in 2020, while the share of population experiencing severe EP issues (i.e., WCI1 equals to 1) decreased from 1.2% in 2017 to 0.6% in 2020. Similar results derive from **Error! Reference source not found.** and **Error! Reference source not found.**, regarding WCI2 and WCI3, respectively.



(a)



(b)

Figure 21. Selected composite EP consensual indices in Riga pilot – (a) Share of population at EP according to WCI1; (b) Share of population at EP according to SCI1

Finally, as shown in Figure 22, the share of population experiencing any type of EP within the pilot area, i.e., inability to keep home warm, arrears on utility bills or leaks, damp walls/floors/foundation is steadily decreasing over time. This indicator shows high percentages as, practically, all individual EP indicators are taken into consideration.

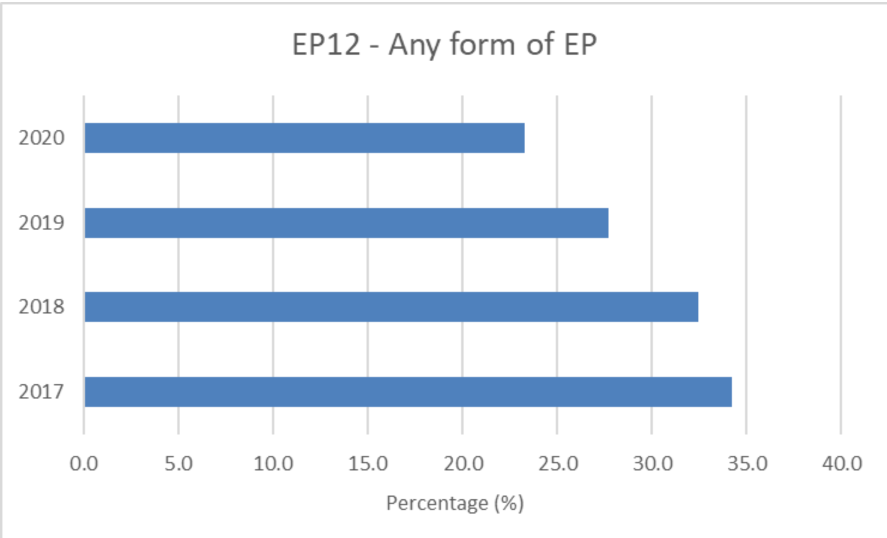
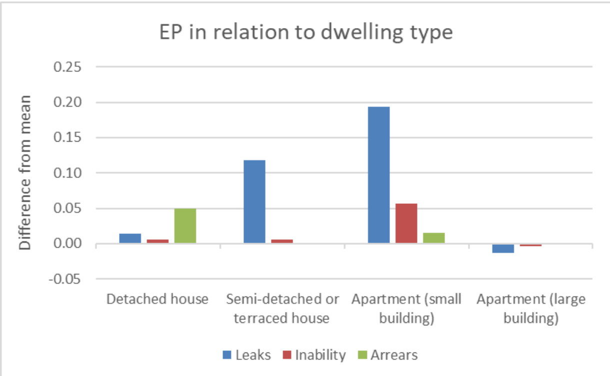


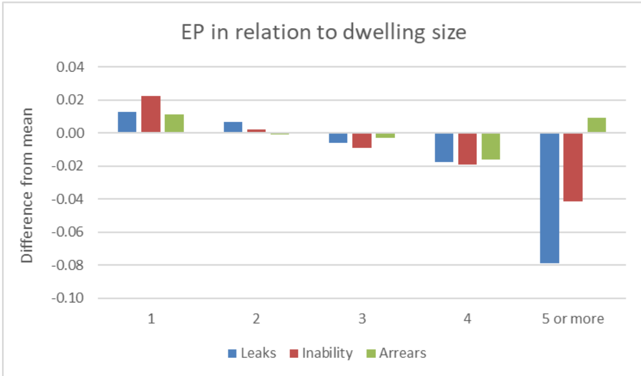
Figure 22. Share of population at EP according to EP12 in Riga pilot

Furthermore, certain housing characteristics and living conditions of households were examined in relation to the above investigated indicators, to explore the effect of these characteristics on EP vulnerability in the pilot area.

As shown in Figure 23, households living in large buildings do not experience EP problems (leaks, inability to keep home adequately warm, arrears on utility bills), apparently, due to their higher incomes on average. On the contrary, households living in semi-detached or terraced houses and those living in small buildings face higher problems with leaks, with those living in small buildings facing also the highest difficulty in keeping their apartments adequately warm. Finally, households living in detached houses are the ones that face higher problems with arrears on utility bills. The dwelling size (in terms of number of rooms) is also related to the three basic EP indicators (leaks, inability to keep home adequately warm, arrears on utility bills). Households living in houses with one room present the highest EP rates compared to the average rate, followed by those living in 2-rooms houses. On the contrary, households living in larger houses (3, 4, 5 or more rooms) present lower EP rates compared to the average, probably due to the higher incomes of these households. It should be noted, though, that households living in large houses (5 or more rooms) seem to face problems with arrears on their utility bills.



(a)

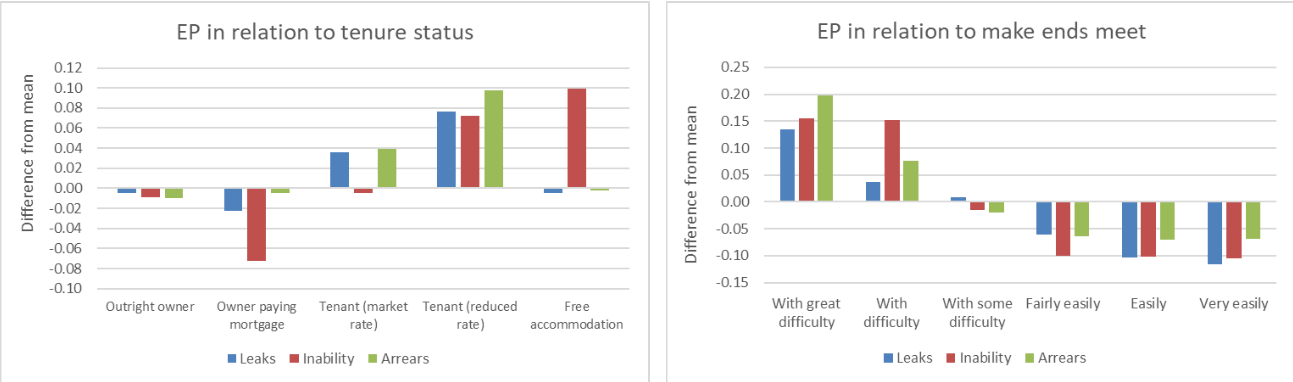


(b)

Figure 23. Leaks, inability to keep house warm and arrears on utility bills in relation to dwelling type (a) and in relation to dwelling size (b) in Riga pilot

As regards tenure status, tenants who pay rent at reduced rate seem to be more prone to energy poverty, followed by tenants who pay rent at market rate. It is also noteworthy that among all groups, those living at free accommodation status are the most vulnerable ones in terms of keeping their home adequately warm. On the other hand, owners seem to face less EP problems with respect to the average rate. The level of difficulty in terms of making ends meet is related to the three EP indicators examined. Specifically, households experiencing great difficulty in making ends meet present higher EP rates of up to 20% versus average rates. On the contrary, households that can easily (fairly easily up to very easily) make ends meet present quite lower EP rates (up to 12%) compared to average rates (Figure 24).

Similar trends are observed in the case of complementary EP indicators.

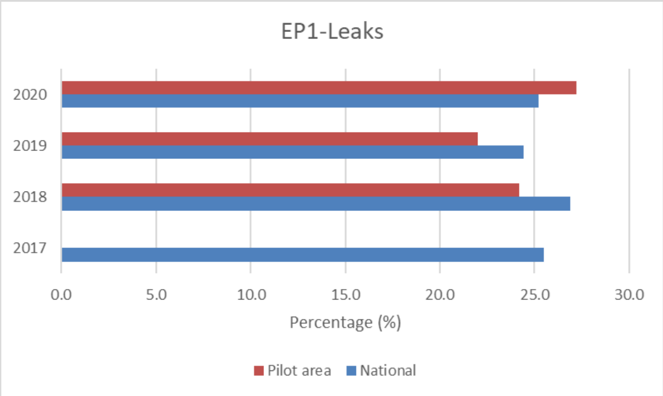


(a) (b)

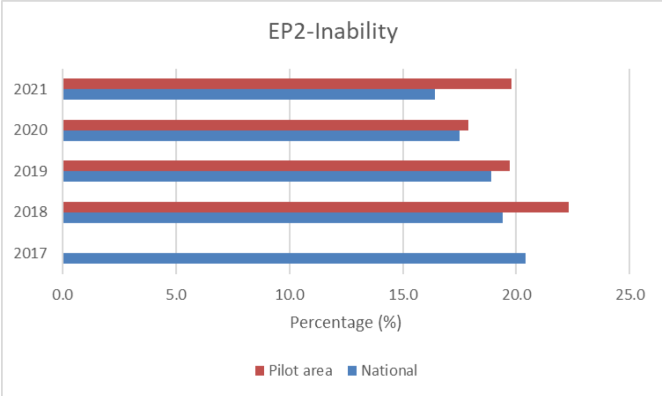
Figure 24. Leaks, inability to keep house warm and arrears on utility bills in relation to tenure status (a) and the level of difficulty in making ends meet (b) in Riga pilot

3.2.4 Energy poverty in the Coimbra Pilot

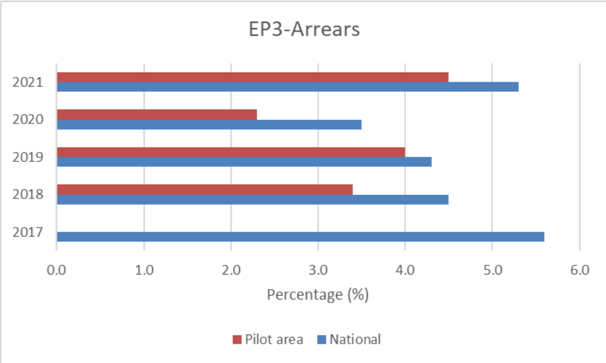
Figure 25 presents the EP rates in the Municipality of Coimbra based on the three main consensual indicators. The percentage of population living in a dwelling with leaks, damp or rot in the Portuguese pilot area is higher than the national average (almost by 2%). It worths noting that leakages-damp problems within the pilot area deteriorated in 2020, marking an increase of up to 23.6%, while also exceeding national rates for the first time. The percentage of population not being able to keep home adequately warm also exceeds the national percentage (almost by 3%) in the pilot area, with the difference between the two rates increasing in 2021 as compared to the last two years. A better condition is observed in the case of EP3 indicator, as fewer households seem to have arrears on their energy bills in the pilot area compared to the national level, in 2021. Still, the picture is worse compared the previous three years, as all rates (both at pilot-area level and national level) were significantly lower.



(a)



(b)



(c)

Figure 25. Consensual EP indicators in Coimbra pilot – (a) Share of total population living in a dwelling with leaks; (b) Share of population not able to keep home adequately warm; (c) Share of population having arrears on utility bills in the past 12 months

Figure 26 illustrates the results of two selected Weighted (WCI) and Simple (SCI) Composite Indices (i.e., WCI1 and SCI1). The energy poverty problem seems to be rather stable over the years according to the three indices. For example, the percentage of the population without EP issues has remained on the order of 60% since 2018, while that with severe EP issues (i.e., WCI1 is equal to 1) has been reduced by 0.3 percentage points since 2018.

Figure 26. Selected composite EP consensual indices in Coimbra pilot – (a) Share of population at EP according to WCI1; (b) Share of population at EP according to SCI1

The percentage of the population facing any type of EP in the pilot area, i.e., inability to keep their house adequately warm, arrears on utility bills, or leaks/damp walls, shows a decreasing trend, according to Figure 27. It is noteworthy that this indicator shows higher rates of energy poverty, as it combines all individual energy poverty indicators.

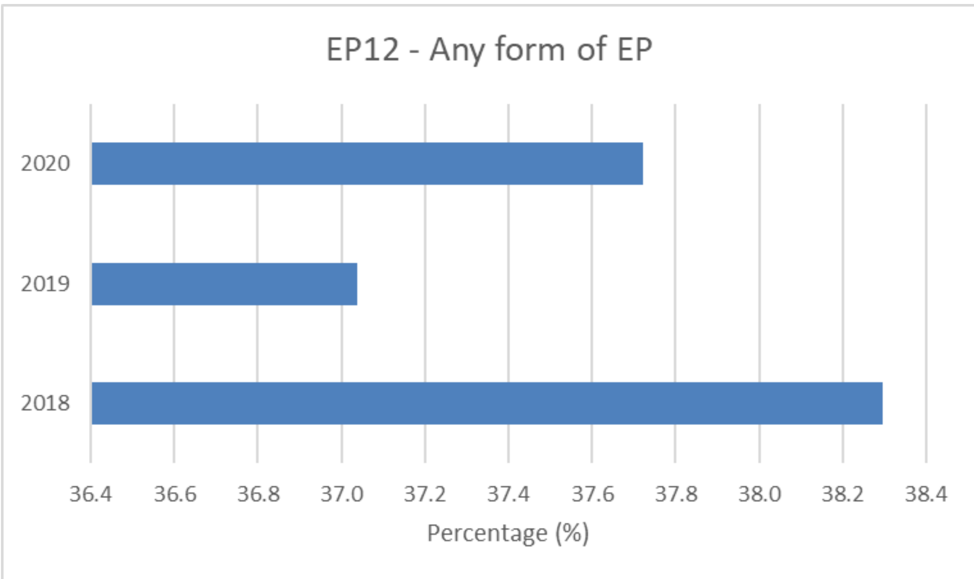
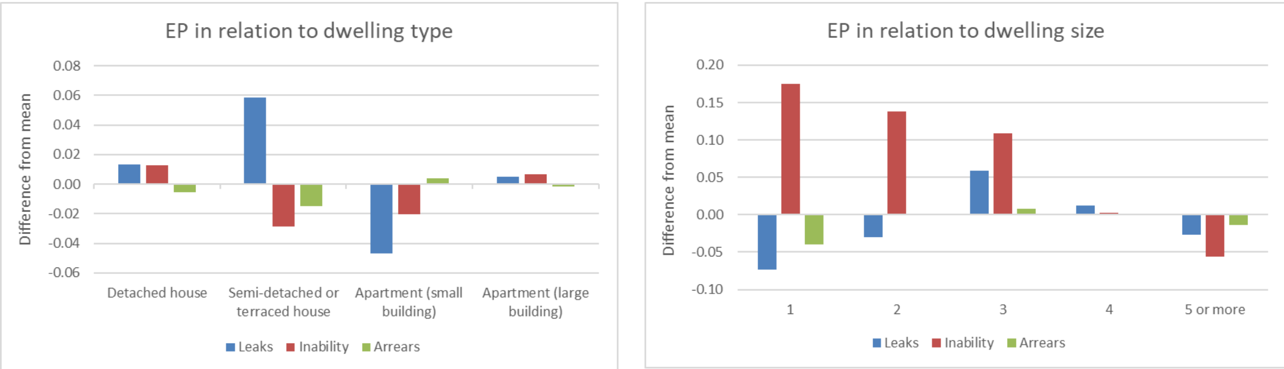


Figure 27. Share of population at EP according to EP12 in Coimbra pilot

Moreover, the relationship between EP vulnerability and certain housing features, as well as living conditions, is explored. As shown in Figure 28, households living in semi-detached houses face the highest problems with leaks/damp walls, while they are less prone to arrears, and they are more capable to keep their house adequately warm. Households living in apartments (small buildings, followed by large buildings) present lower EP issues, on average, as compared to the average rates. The dwelling size is also related to the three basic EP indicators. Households living in one-room house present the highest problems in terms of leaks/damp walls compared to the average, while they are less prone to the other two indicators, on average. Households living in houses with four or more rooms have the lowest EP rates, probably due to the income of these households.

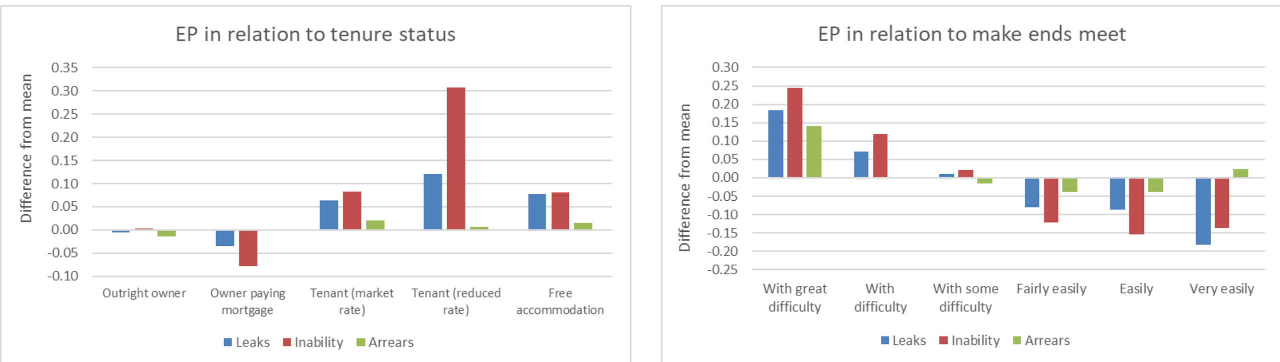


(a) (b)

Figure 28. Leaks, inability to keep house warm and arrears on utility bills in relation to dwelling type (a) and in relation to dwelling size (b) in Coimbra pilot

Also, according to Figure 29, the most vulnerable groups to EP are tenants who pay rent (either at market or at reduced rate) and households living at free accommodation. It should be noted though that tenants who pay rent at reduced rate are the most vulnerable ones in terms of keeping their home adequately warm. Finally, households experiencing difficulty and great difficulty in making ends meet face also higher EP issues, with differences in EP rates of up to 25% in comparison with average rates. On the other hand, households that can easily make ends meet present quite lower EP rates, of up to 15% versus average rates.

As regards complementary EP indicators and certain housing features examined corresponding conclusions are drawn.



(a) (b)

Figure 29. Leaks, inability to keep house warm and arrears on utility bills in relation to tenure status (a) and the level of difficulty in making ends meet (b) in Coimbra pilot

3.2.5 The impact of Covid-19 on household EP

The Covid-19 pandemic period was accompanied by shorter or longer periods of lockdowns, which had a twofold effect. On the one hand, many economic activities were curtailed, leading in many cases to a reduction in household incomes. On the other hand, restrictions even on daily walks for leisure activities, shopping for goods, etc. and distance learning and working led to more hours spent at home and greater use of electrical and electronic appliances, lighting and heating systems.

What was therefore expected was a significant increase in energy poverty levels, due to falling income and rising energy consumption. For example, a survey, carried out within the STEP-IN project and based on real-time measurements of energy consumption in households in a mountainous settlement in Greece[2], observed that the hourly average electrical consumption between October 2020 (before the second lockdown in Greece) and November 2020 (during the second lockdown) increased by about 24% (Figure 30). Moreover, the average increase in the operating hours of the heating systems was 1.3 (ranging from 0.1 to 3 hours per day).

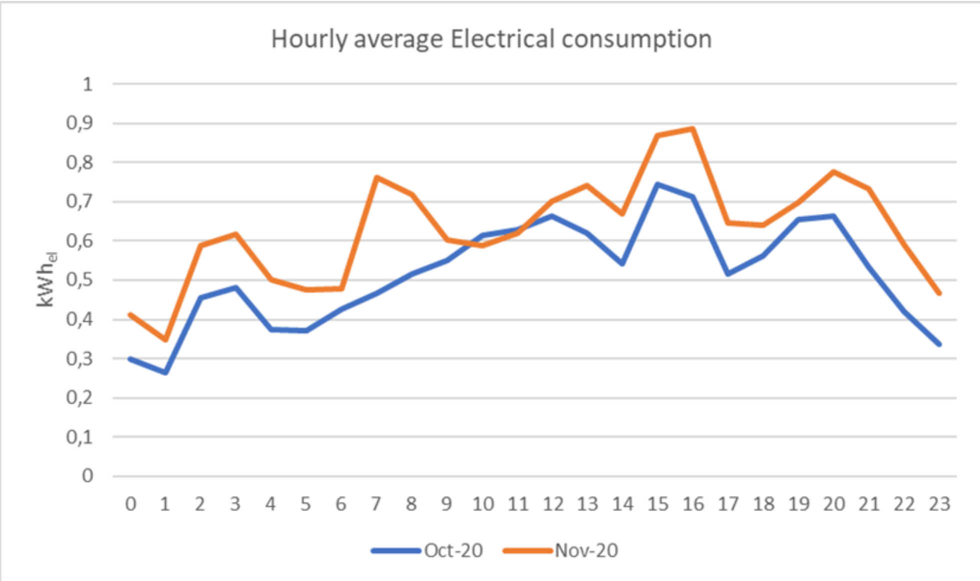


Figure 30. Hourly average electricity consumption before and after the implementation of the second lockdown (Source: STEP-IN project, Deliverable 3.3)

Nevertheless, significant differences existed among households with different incomes. Comparing two households of different income with 4 members (two adults and two children), it was found that the high-income class household presented an average increase in electricity consumption of around 7 kWh per day (or 118%) and indoor temperature of 2°C (or 10%) during the lockdown. On the contrary, the low-income household had a decrease in electricity consumption around 0.8 kWh per day (or 8%) on average and a negligible increase in indoor temperature 0.1°C (0.6%).

[2] STEP-IN project (2021). D3.3 – Data analysis Report on Mountain Living Lab. Available at: https://www.step-in-project.eu/wp-content/uploads/D3.3-Data-analysis-report-Mountain-Living-Lab.pdf

However, an examination of the recorded energy poverty indicators before, during and after the pandemic period shows that there has not been the expected deterioration of the problem. The graphs below (Figure 31 and Figure 32) show the two widely used EP indicators for Member States and the EU-27 (i.e., Inability to keep home adequately warm and Arrears on utility bills) for the period 2018-2022. It is evident that in the majority of Member States, i.e., in 16 Member States in 2020 and in 19 Member States in 2021, the share of energy poor households decreased during the pandemic years.

However, in some countries, such as Spain and Germany, there have been notable increases in energy poverty rates (e.g., the Inability to keep home adequately warm index increased, in 2020, by 50% in Spain and by 180% in Germany).

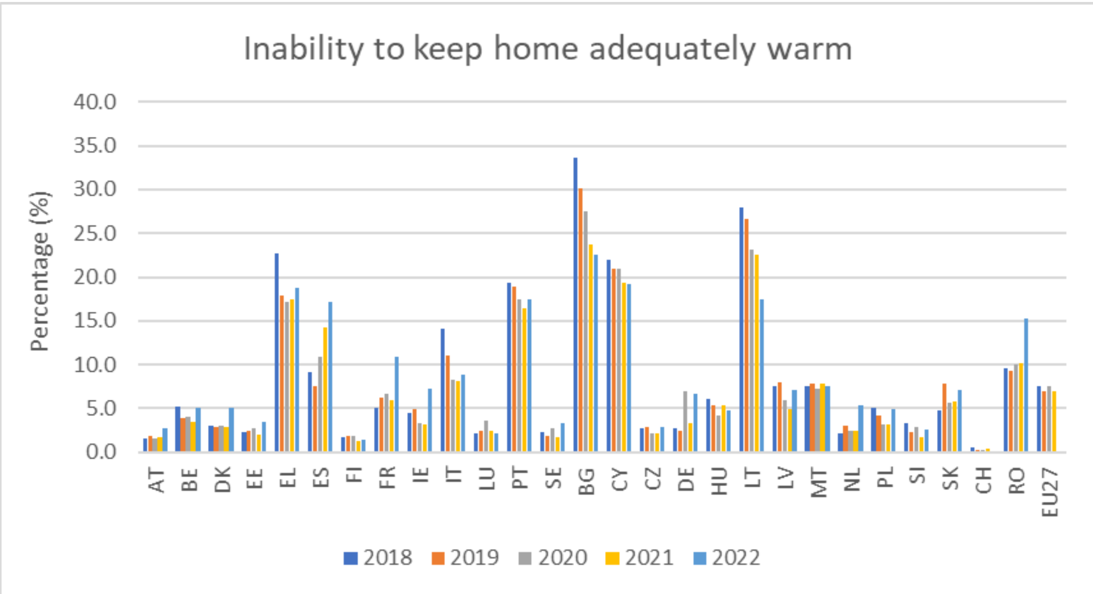


Figure 31. Share of households unable to keep their home adequately warm by MS from 2018 to 2022

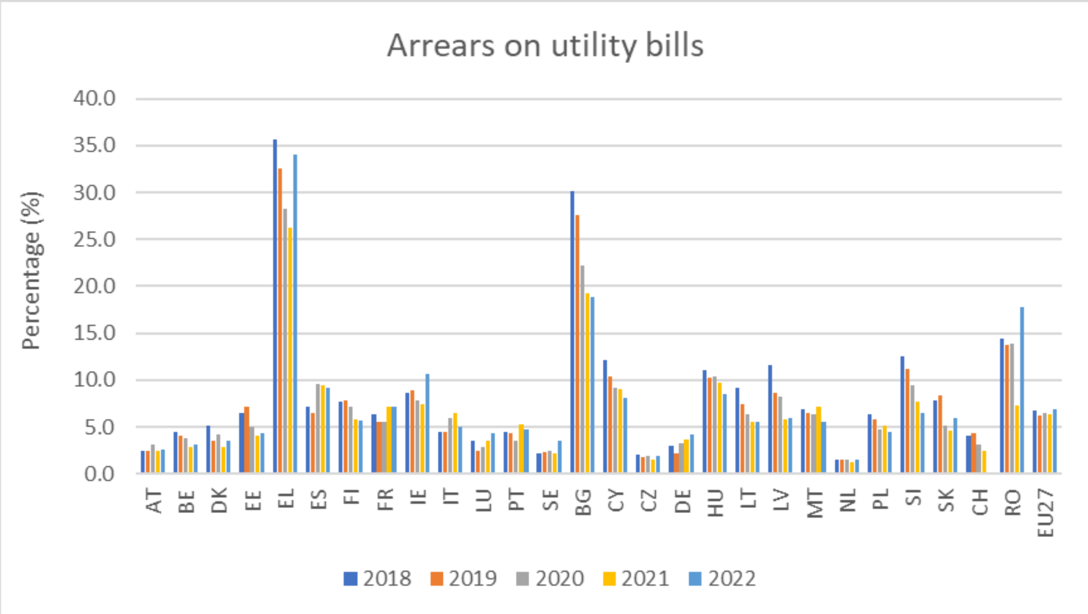


Figure 32. Share of households with arrears on utility bills by MS from 2018 to 2022

Focusing on the four REVERTER pilots, the share of EP in the general population is decreasing over time (Figure 33 to Figure 40). This trend is also observed for the pandemic period, but with exceptions (i.e., in Brezovo, in 2021, for the 'Arrears' indicator, and in Coimbra in 2021 for both indicators). Even in these cases, the absolute increase in the two specific EP indicators is between 0.8-2.2%. Nevertheless, the data are for vulnerable households (for this analysis, households that declared in the EU SILC survey that are facing difficulties or great difficulties to make ends meet have been taken into account). In particular, in Brezovo the percentage of households in arrears increases to 2.7% (from 0.8% for the general population). In Riga, the corresponding indicator increases by 0.7% (from -0.7% for the general population) and Indicator B by 1.7% (from -1.6% for the general population). Finally, in Coimbra, the arrears index increases by 6.2% (from 1.9% for the general population) and the B index by 10% (from 2.2% for the general population).

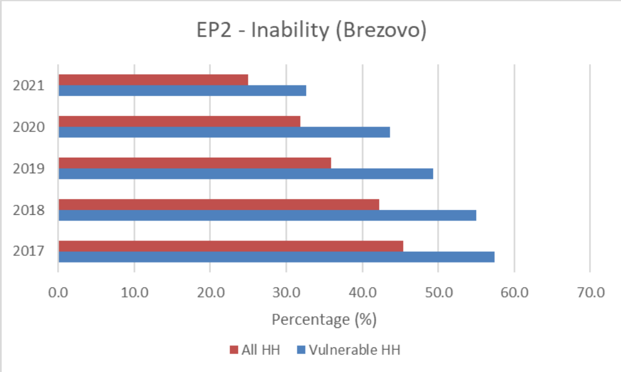


Figure 33. Share of total and vulnerable households unable to keep their home adequately warm in Brezovo from 2017 to 2021

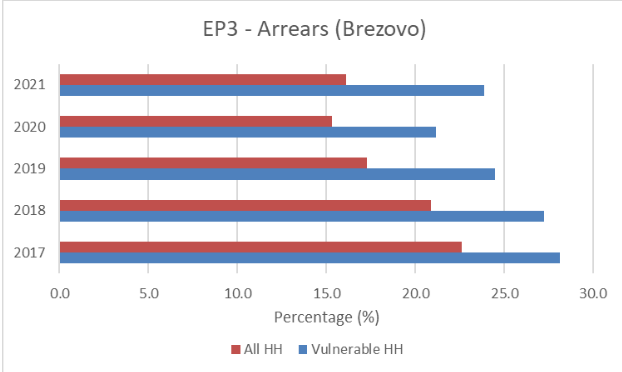


Figure 34. Share of total and vulnerable households with arrears on utility bills in Brezovo from 2017 to 2021

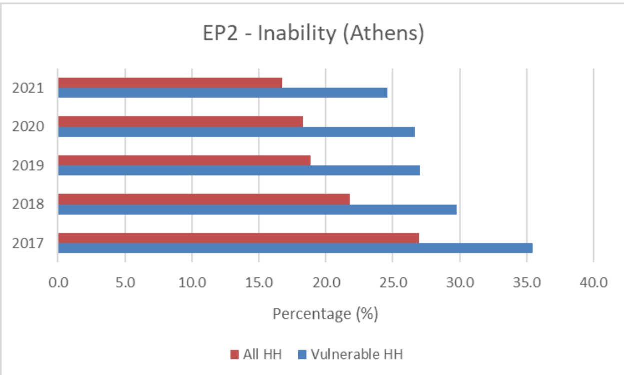


Figure 35. Share of total and vulnerable households unable to keep their home adequately warm in Athens Urban Area from 2017 to 2021

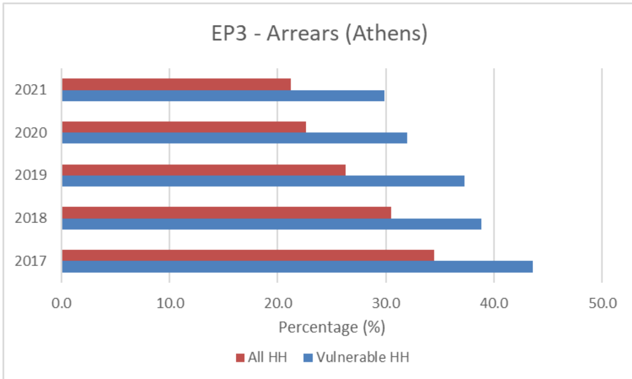


Figure 36. Share of total and vulnerable households with arrears on utility bills in Athens Urban Area from 2017 to 2021

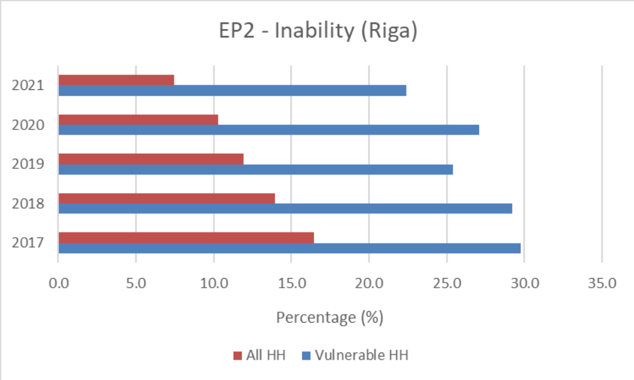


Figure 37. Share of total and vulnerable households unable to keep their home adequately warm in Riga from 2017 to 2021

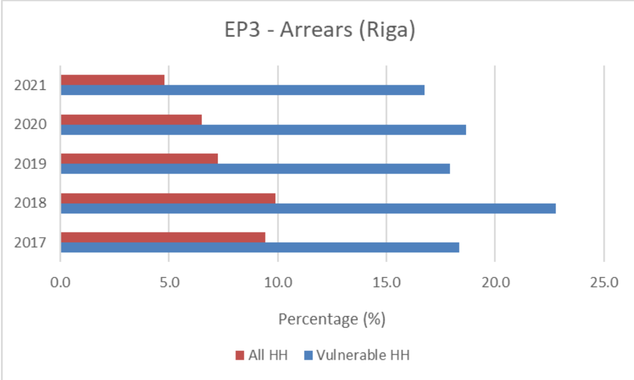


Figure 38. Share of total and vulnerable households with arrears on utility bills in Riga from 2017 to 2021

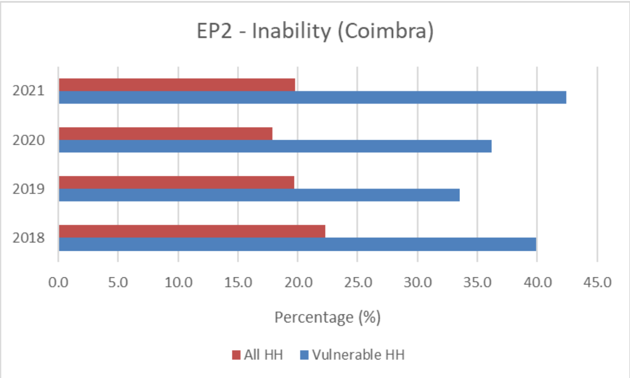


Figure 39. Share of total and vulnerable households unable to keep their home adequately warm in Coimbra Municipality from 2017 to 2021

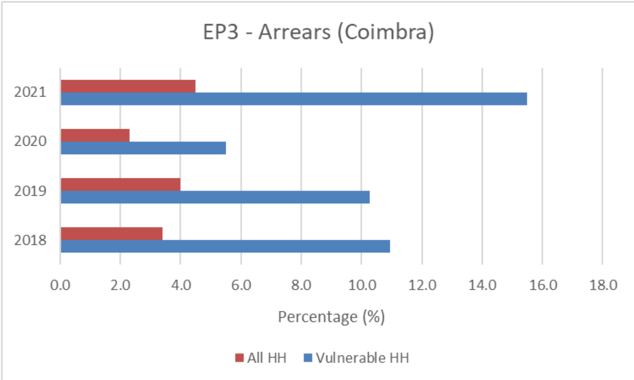


Figure 40. Share of total and vulnerable households with arrears on utility bills in Coimbra Municipality from 2017 to 2021

The two main reasons why the problem was contained, in most Member States, were the reduction in fuel prices (which were maintained until around mid-2021, before prices - especially gas prices - started to rise again) mainly stemmed from the negative impact of the pandemic on the demand for energy, e.g., electricity consumption in the EU-27 declined by 11% year-on-year in Q2 2020 (European Commission, 2020) and the measures taken by Member States to support consumers, especially the vulnerable ones.

Energy commodity prices experienced a significant decline at the outset of the pandemic, as illustrated in Figure 41. Notably, the Brent crude oil price plummeted by 75% from February to April 2020, while the Dutch TTF gas price saw a 44% decrease (Kuik et al., 2022). Consequently, wholesale electricity prices in the euro area witnessed a substantial drop of 30-50% in the first half of 2020 compared to 2019, reaching levels not observed in over a decade (European Commission, 2020). However, Figure 42 depicts that, in certain Member States, the reduction in wholesale prices was not directly reflected in retail prices.

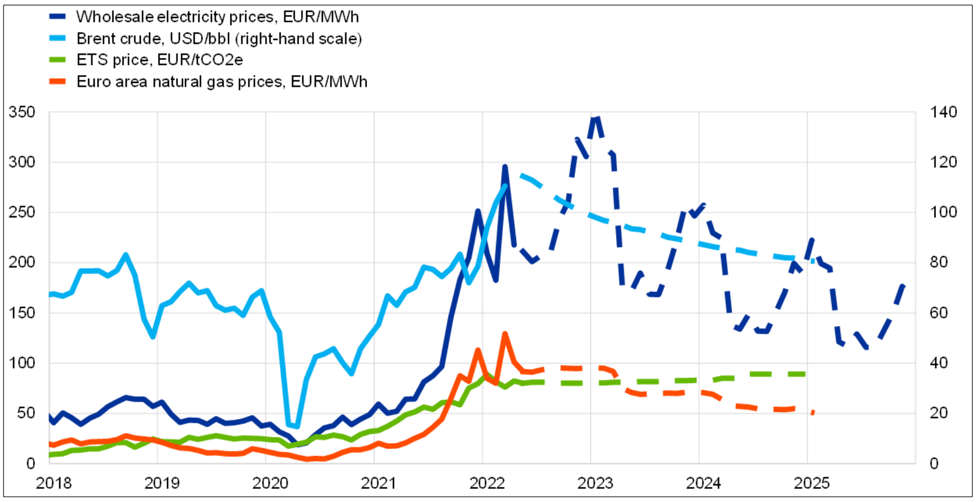


Figure 41. Pandemic-related drop in energy prices (Source: (Kuik et al., 2022)

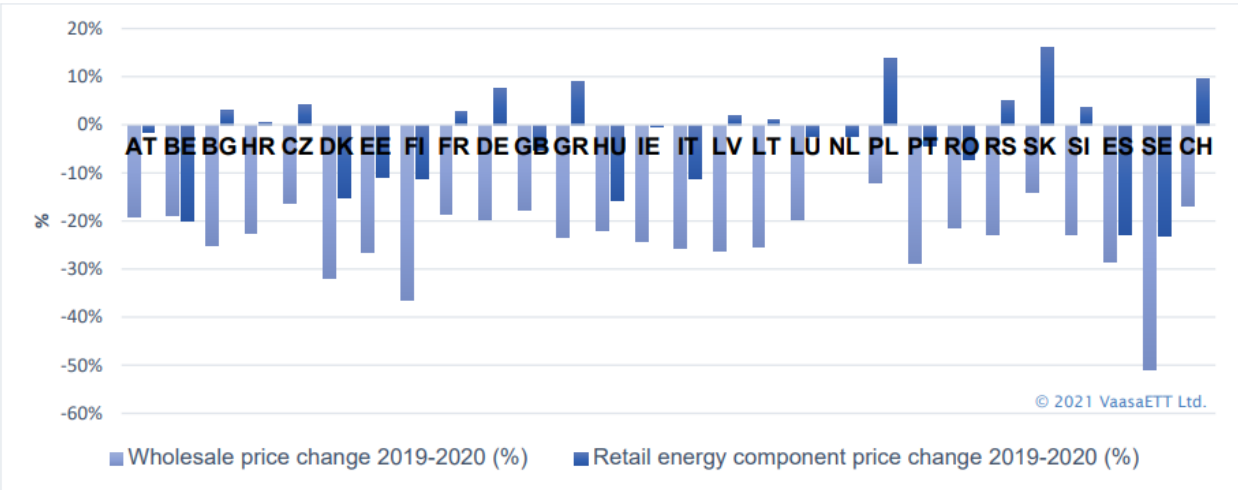


Figure 42. Wholesale vs residential energy component price change from 2019 to 2020 - annual averages, in % (Source: (Grigoriou et al., 2021)

Nearly all European countries implemented measures to mitigate the pandemic's adverse effects on households in general, with a particular focus on shielding vulnerable consumers. A notable majority of Member States and associated countries enforced a moratorium on disconnecting energy consumers. This moratorium was often coupled with options for deferring energy bill payments without incurring penalties or offered staggered payment plans. Certain Member States adopted direct financial assistance measures, such as providing free fuel vouchers, to alleviate the burdens on vulnerable households. In other instances, Member States intervened by reducing levies and/or taxes or facilitating access to social tariffs, either by extending application timescales or granting automatic extensions (Council of European Energy Regulators, 2021). Figure 43 presents a comprehensive overview of all measures undertaken in 2020 that directly influenced retail prices, delineating state/regulatory initiatives from those driven by market players.

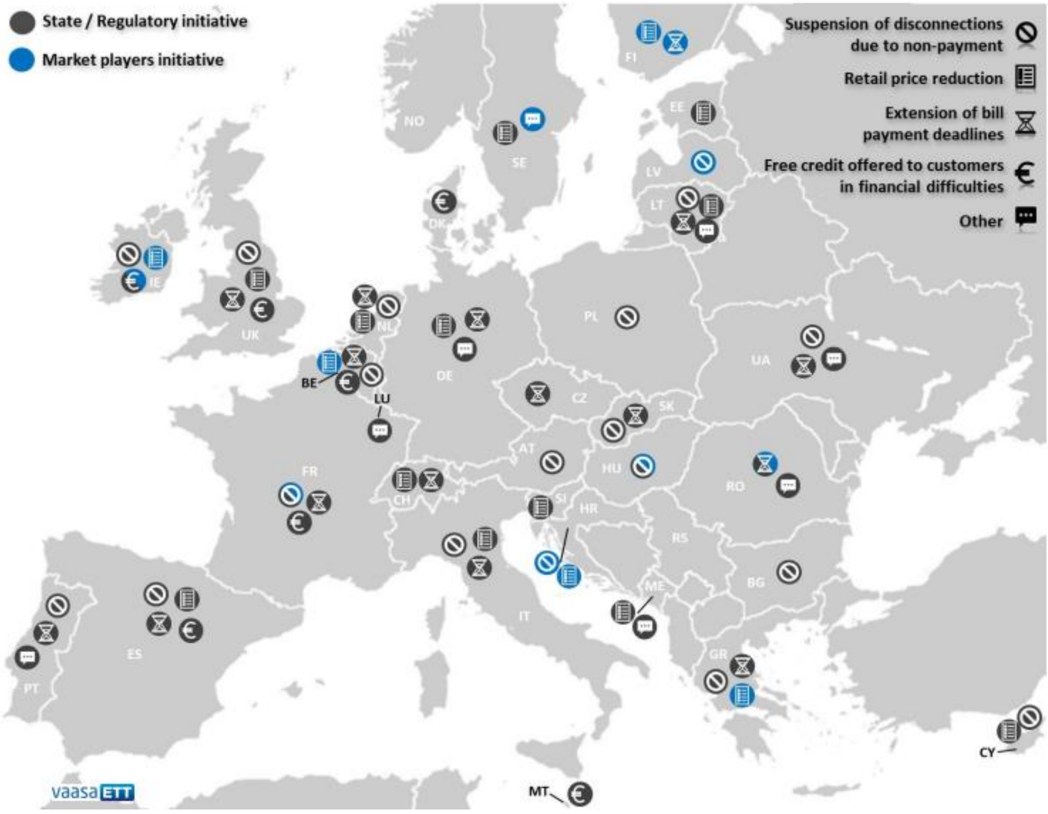


Figure 43. Supportive measures taken during the COVID-19 pandemic in European countries in 2020 (Source: (Grigoriou et al., 2021)

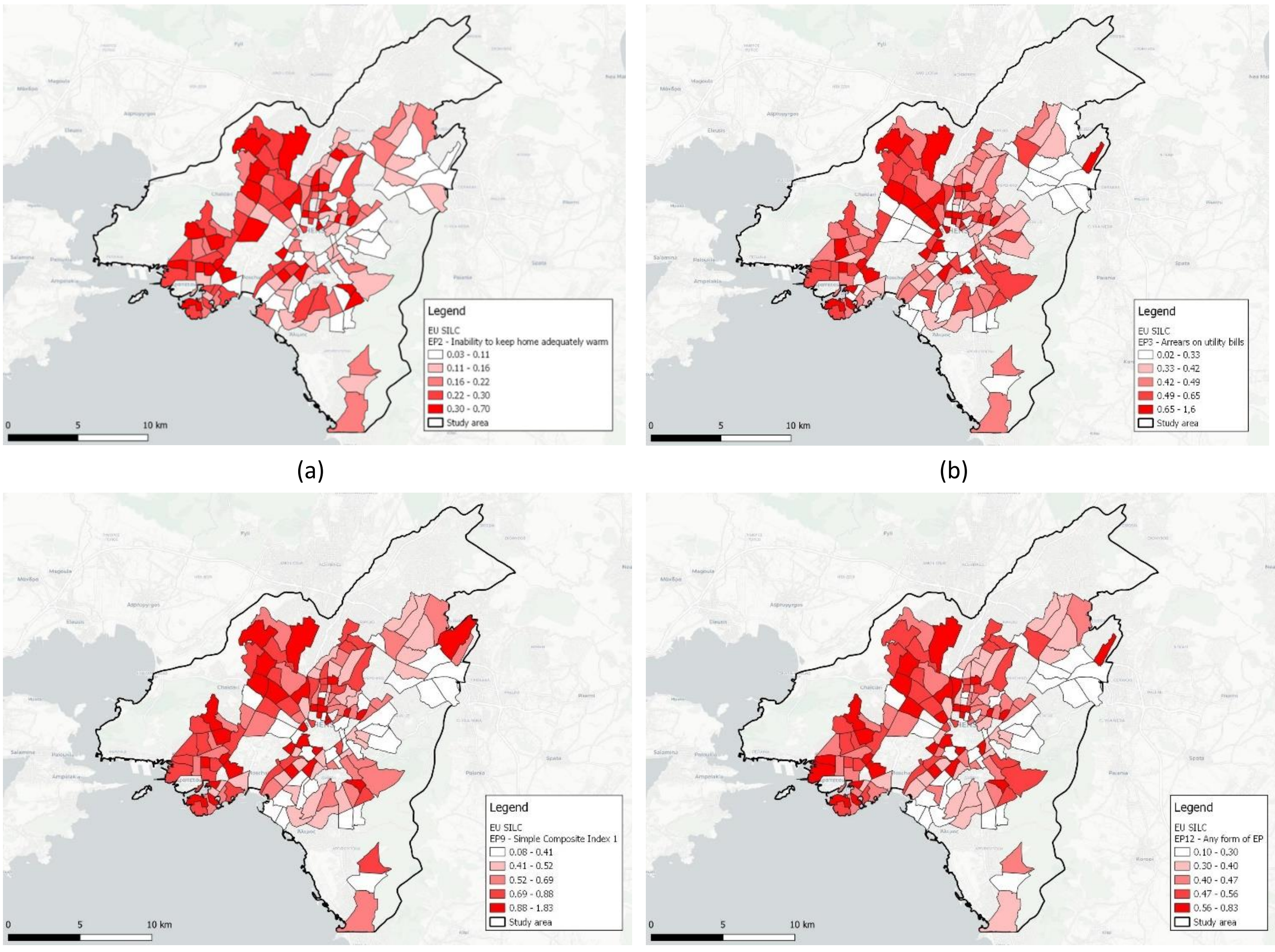
3.3 State-of-the-art tools in EP analysis and prediction

3.3.1 EP mapping

It is commonly acknowledged that EP indicators allow for generic country or region comparisons, but they obscure the immense spatial complexity of EP. Area-based, i.e., spatial, approached have potential to identify and quantify EP at the local level. Previous efforts at national, regional, city and neighbourhood levels (Encinas et al., 2022; Gupta & Gregg, 2018; Mulder et al., 2023; Walker et al., 2012; Zaman et al., 2023) have identified evidence of spatial concentration of EP, in some cases more intense that income poverty and socioeconomic inequality.

To illustrate this spatial character of EP, the Athens Urban Area pilot was used. The spatial analysis and EP mapping was carried out only for this pilot for two reasons. First, there were a significant number of observations from the EU SILC and HBS national samples unlike in the other pilots, due to the fact that a significant proportion of the Greek population resides in the study area. Second, the zip codes of the sample households were provided by the Hellenic Statistical Authority, in compliance with all GDPR requirements. Zip codes as spatial units have such a strong geographical context and their use for spatial, demographic, and socio-economic analysis is increasing (Grubesic, 2008). On the other hand, using zip codes for spatial analysis faces also several problems (many clustered streets are non-contiguous, the size and shape of the spatial units may affect some statistical outcomes, etc.). Another problem that arose in this case was the absence of observations in a number of zip codes.

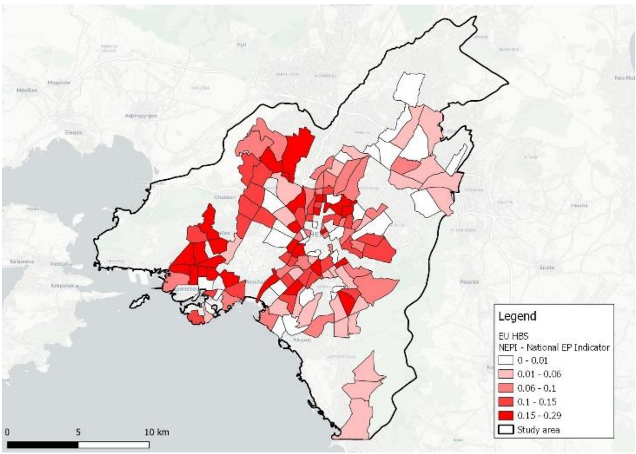
The following figures map the share of selected consensual (Figure 44) and expenditure-based (Figure 45) EP indicators using aggregated data by zip code for all years, i.e., 2017-2021.



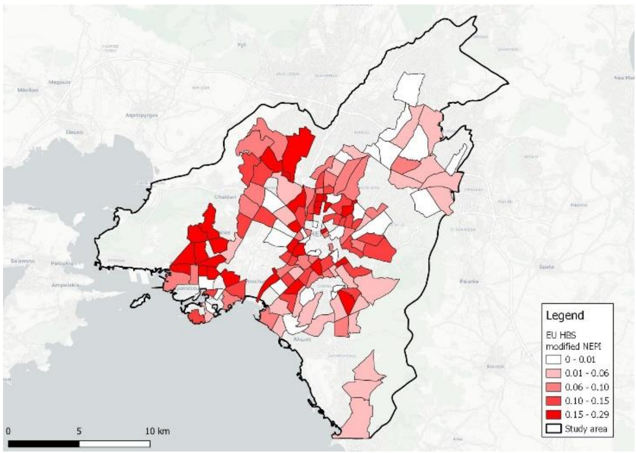
(a) (b)

(c) (d)

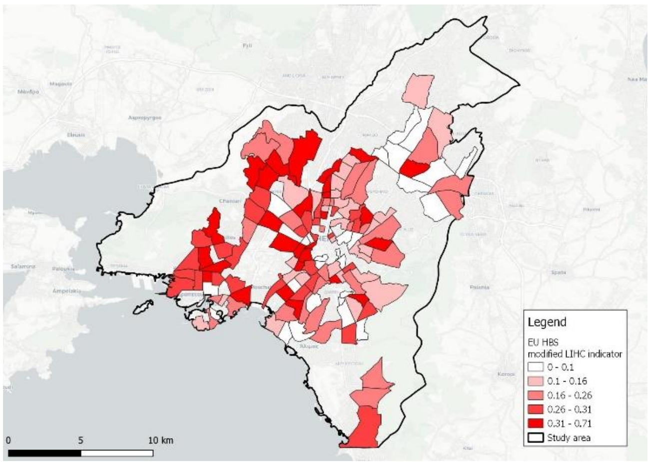
Figure 44. EP incidence at zip code level – (a) EP2-Inability to keep home warm; (b) EP3-Arrears on utility bills; (c) EP9-Simple Composite Index 1; (d) EP12-Any form of EP



(a)



(b)



(c)

Figure 45. EP incidence at zip code level – (a) NEPI; (b) Modified NEPI; (c) Modified LIHC

The above maps show that there are areas (spatial units) with very low or low rates of energy poverty (mainly in North and South Athens) and areas with high rates of energy poverty, regardless of the EP indicator considered (mainly in Central and West Athens and Piraeus region). Areas where the EP problem is directly related to the EP indicator under consideration are also identified.

In an effort to identify "worst first" EP hotspots, i.e., spatial units where EP is related to poor buildings' energy efficiency and low-income households, an EP risk map was created. For this purpose, ten income classes were initially created, using the median income per year. Subsequently, three new risk income classes were created from the 10 classes:

- Low-risk income class – it includes the three highest income classes (incomes above 140% of median income)
- Medium-risk income class – it includes the four middle income classes (incomes between 60% and 140% of median income)
- High-risk income class - includes the three lowest income classes (incomes below 60% of median income)

Also, three risk classes were constructed with respect to the energy efficiency of dwellings, as follows:

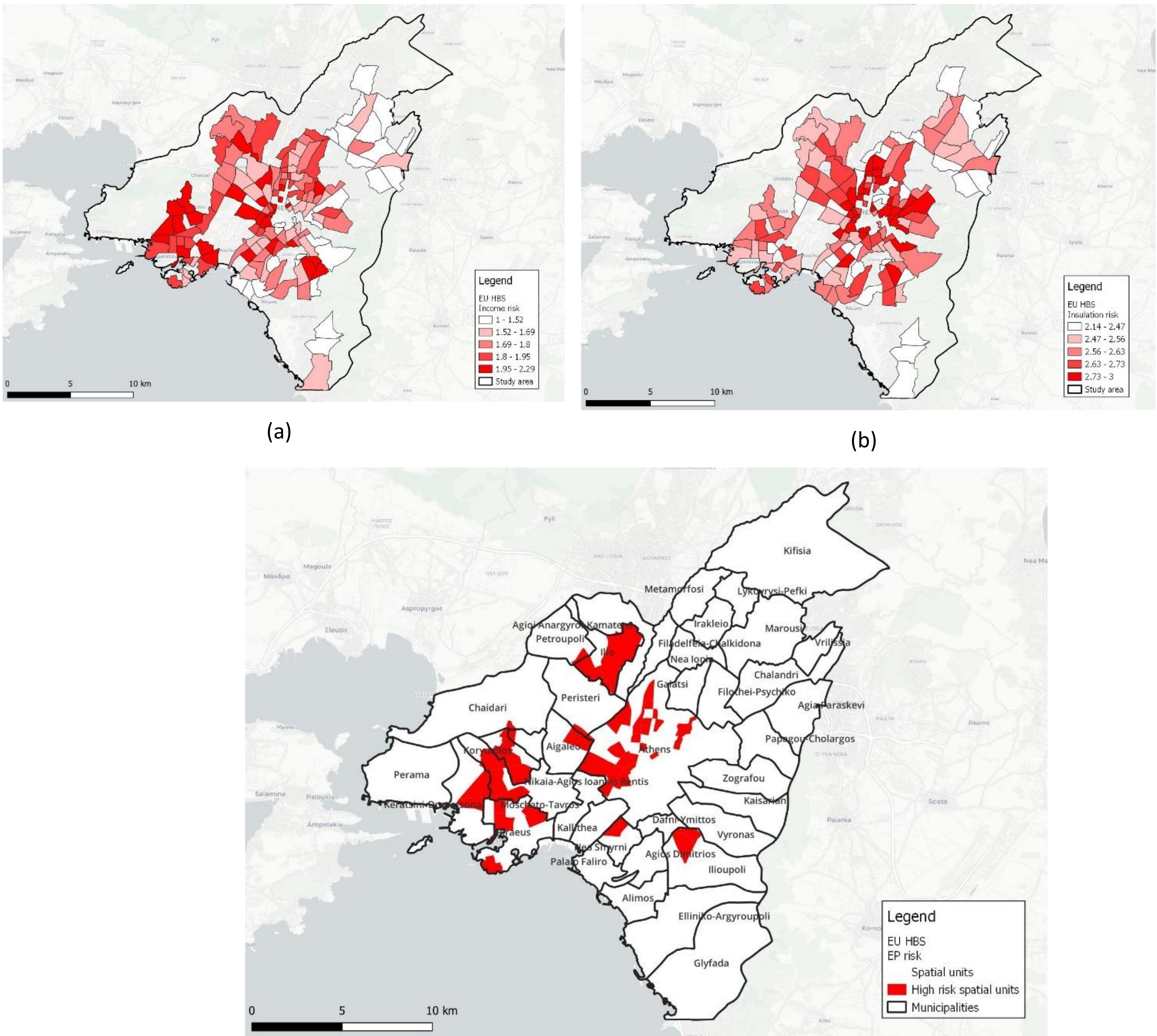
- Low-risk energy efficiency class - it includes houses built after the commencement of the Hellenic Regulation on the Energy Performance of Buildings (KENAK), i.e. after the October 1st, 2010.
- Medium-risk energy efficiency class - includes houses built before the commencement of KENAK and after the first Thermal Insulation Code of 1981 in Greece.
- High-risk energy efficiency class - includes houses built before the first Thermal Insulation Code.

The results are presented in Figure 46. A total of 37 spatial units face a very high risk of EP[3]. About 60% (i.e., 22 out of 37) spatial units are located in Athens Municipality (Central Athens) (Table 10). Furthermore, 4 spatial units are located in Piraeus Municipality (Piraeus region), 3 in Nikaia-Agios Ioannis Rentis Municipality (Piraeus region), and 2 spatial units are located in in Ilioupoli (Central Athens), Ilion (West Athens), Korydallos (Piraeus region), and Keratsini-Drapetsona (Piraeus region) Municipalities. Practically, all municipalities of the Piraeus region have areas with a very high risk of EP (the Municipality of Perama is absent because there are no observations from the EU SILC and HBS surveys, but it is an area with old houses and a relatively high percentage of low-income households).

Table 10. Number of high-risk EP spatial units by Municipality

Municipality	Number of spatial units
Athens	22
Piraeus	4
Nikaia-Agios Ioannis Rentis	3
Ilioupoli	2
Ilion	2
Korydallos	2
Keratsini-Drapetsona	2

[3] High-risk areas relate to three combinations: High-risk income class & High-risk energy efficiency class; High-risk income class & Medium-risk energy efficiency class; High-risk income class & Medium-risk energy efficiency class.



(a) (b)

(c)

Figure 46. EP risk map – (a) Income risk; (b) Energy efficiency risk; (c) High risk spatial units

Finally, the Moran's I metric was used to identify spatial autocorrelation, i.e., a signal that the distribution of a variable is not random in space, and, thus, clusters of similar values are formed. These clusters can be visualised in the Local Indicators of Spatial Association (or LISA) cluster maps. For illustrative purposes, only the analysis for the consensual EP indicators is presented. Spatial autocorrelation is observed on all four indicators (i.e., EP2, EP3, EP9 and EP12). EP3 shows the highest value (Moran's I = 0.217). The LISA cluster maps are presented in Figure 47.

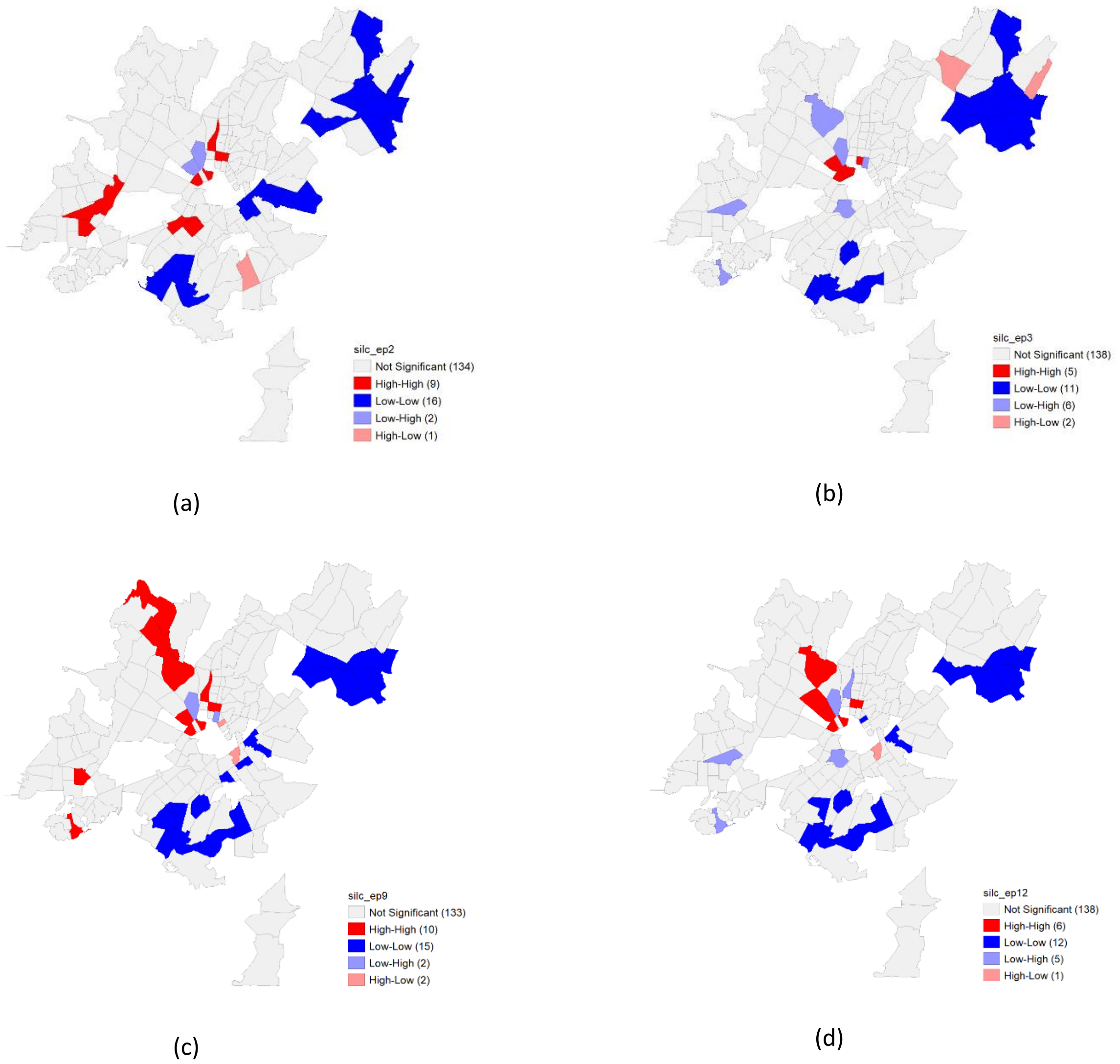


Figure 47. LISA cluster maps for selected EP indicators – (a) EP2-Inability to keep home warm; (b) EP3-Arrears on utility bills; (c) EP9-Simple Composite Index 1; (d) EP12-Any form of EP

The LISA maps reveal regions (clusters) where neighbouring spatial units with correspondingly high (red colour) or low (blue colour) EP rates are located, regions where spatial units with low EP rates are adjacent to spatial units with high values (light blue colour) and, finally, regions where spatial units with high EP rates are adjacent to spatial units with low values (pink colour). Again, areas in North and South Athens present low EP potential, whereas areas in Central and West Athens and in Piraeus region present high EP potential. It is noted that clusters may not be prevalent in all observations, but this is often the case in socio-economic variables, particularly when dealing with limited data. The primary objective is to initially explore the presence of spatial autocorrelation in the EP phenomenon and subsequently pinpoint the locations where discernible patterns emerge.

3.3.2 Analysing EP drivers using multivariate regression analysis

Several multivariate regression models were tested to examine the relationship between EP indicators and commonly referred drivers. Specifically, models using consensual-based EP indicators as the dependent variable were estimated for all four pilots. Nevertheless, the performance of these models in terms of goodness of fit and classification was poor (e.g., in the best models the "successful" classification of EP households was around 20%). The main reason for the poor performance of these models is the so-called omitted variables bias. The EU SILC dataset lacks information which is important for EP predictions, such as the year of construction of the house or important household characteristics (e.g., household size and composition).

Therefore, the multivariate regression analysis focused on expenditure-based indicators calculated by the HBS dataset. As mentioned, the Bulgarian HBS dataset did not include derived variables at household level (e.g., household size and type, equivalent size, number of persons per age class, number of persons who are working or are unemployed, etc.). Consequently, the multivariate analysis was limited to the Greek HBS dataset.

Focusing on the Greek HBS dataset analysis, three indicators were explored, namely the official EP indicator (NEPI) and the two new indicators developed by REVERTER, the modified NEPI and the modified LIHC, using binary logistic models. The alternative models were examined with model fit statistics including goodness of fit and Pseudo R^2, as well as classification metrics, namely sensitivity, specificity, and overall accuracy. Sensitivity, also referred to as the true positive rate, denotes in this case the percentage of energy-poor households accurately identified as such, whereas specificity, known as the true negative rate, represents the percentage of non-energy-poor households correctly classified. The objective is to maximise both sensitivity and specificity; however, as the threshold probability becomes lower, the true positive rate is enhanced but the true negative rate concurrently diminishes. Overall accuracy is the fraction of predicted values that are successful. These three metrics are calculated by the confusion matrix (Figure 48) using the following equations:

Sensitivity = TP / (TP + FN)

Specificity = TN / (FP + TN)

Accuracy = TP + TN / (TP + FP + FN + TN)

		Actual values	
		Energy poor	Non-energy poor
Predicted values	"Successful" classification	True positives (TP)	False positives (FP)
	"Unsuccessful" classification	False negatives (FN)	True negatives (TN)

Figure 48. The confusion matrix

The best-fit models are shown in the following tables (Table 11 to Table 13).

Table 11. Binary logistic regression results - NEPI

Variables	Coef.	Odds Ratio
HH income	-0.522*** (0.0208)	0.593*** (0.0124)
HH total members	1.553*** (0.0904)	4.725*** (0.427)
Kids (<4 years old)	-1.005*** (0.336)	0.366*** (0.123)
Elderly people (>65 years old)	0.592*** (0.145)	1.808*** (0.262)
Unemployed members	0.949*** (0.159)	2.584*** (0.410)
Free accommodation	0.446** (0.199)	1.563** (0.311)
Tenant – market rent	-1.085*** (0.159)	0.338*** (0.0539)
Dwelling area	0.00908*** (0.00213)	1.009*** (0.00215)
Year of construction	-0.320*** (0.0600)	0.726*** (0.0436)
Constant	1.511*** (0.308)	4.533*** (1.394)
Observations: 6,645	**Log likelihood: -948.465**	**Pseudo R^2: 0.5598**

Std. Err. in parentheses; *** p<0.01, ** p<0.05, * p<0.1

Table 12. Binary logistic regression results – modified NEPI

Variables	Coef.	Odds Ratio
HH income	-0.530*** (0.0211)	0.588*** (0.0124)
HH total members	1.626*** (0.0917)	5.084*** (0.466)
Kids <4 years old	-1.245*** (0.340)	0.288*** (0.0980)
Elderly people (>65 years old)	0.359** (0.144)	1.432** (0.206)
Unemployed members	0.918*** (0.158)	2.505*** (0.396)
Free accommodation	0.438** (0.201)	1.550** (0.311)
Tenant – market rent	-1.289*** (0.164)	0.276*** (0.0451)
Dwelling area	0.0123*** (0.00209)	1.012*** (0.00212)
Year of construction	-0.452*** (0.0614)	0.636*** (0.0391)
Constant	1.874*** (0.309)	6.512*** (2.011)
Observations: 6,645	**Log likelihood: -940.168**	**Pseudo R^2: 0.5715**

Std. Err. in parentheses; *** p<0.01, ** p<0.05, * p<0.1

Table 13. Binary logistic regression results – modified LIHC

Variables	Coef.	Odds Ratio
HH income	-0.680*** (0.025)	0.505*** (0.0125)
HH total members	5.407*** (0.196)	223.122*** (43.62)
Kids <4 years old	-2.577*** (0.342)	0.076*** (0.026)
Elderly people >65 years old	0.35* (0.142)	1.242* (0.201)
Unemployed members	1.024*** (0.144)	2.784*** (0.400)
Detached house	0.835*** (0.164)	2.303*** (0.377)
Semi-detached house	0.760*** (0.228)	2.139*** (0.487)
Dwelling area	0.010*** (0.002)	1.010*** (0.002)
Year of construction	-0.421*** (0.0623)	0.656*** (0.040)
Constant	-2.064*** (0.287)	0.126*** (0.036)
Observations: 6,645	**Log likelihood: -887.940**	**Pseudo R^2: 0.7443**

Std. Err. in parentheses; *** p<0.01, ** p<0.05, * p<0.1

Moreover, Table 14 summarises the performance of the models in terms of prediction accuracy.

Table 14. Prediction performance of the "best estimate" models

	NEPI	Modified NEPI	Modified LIHC
Sensitivity	58.16%	59.56%	86.03%
Specificity	98.08%	98.12%	97.38%
Accuracy	94.10%	94.18%	94.91%

As far as the overall performance of the models is concerned, the most promising results are obtained from the modified LIHC model. Specifically, it presents the highest goodness of fit ratio, with a Pseudo R^2 of 74.4% and the highest sensitivity (i.e., the percentage of energy-poor households accurately identified as such), about 86%, and the highest overall accuracy, about 95%.

The explanatory variables in all three models are related to both household and house characteristics. In the cases of the NEPI and modified NEPI models, the explanatory variables are identical. None of these models include variables related to the type of dwelling but both models include tenure status variables, i.e., tenants paying rent at market rate (Tenant-market rent, binary variable: 1 if tenant, 0 otherwise) and accommodation which is provided for free by the family or others (free accommodation, binary variable: 1 if free accommodation, 0 otherwise).

In the modified LIHC model, some of the explanatory variables are common to the two other models, namely:

- household income (HH income, continuous variable - HH099 in HBS),
- total number of household members (HH total members; integer variable – HB05 in HBS),
- presence of kids less than 4 years old (Kids <4 years old; binary variable: 1 if there are kids less than 4 years old, 0 otherwise),
- presence of elderly people (Elderly people >65 years old; binary variable: 1 if there are people over 65 years old, 0 otherwise),
- presence of unemployed household members (Unemployed members; binary variable: 1 if there are unemployed household members, 0 otherwise),
- area of the house (dwelling area; continuous variable – DS017 in HBS),
- year of construction of the house (Year of construction – integer variable[4] – DS018 in HBS)

In the same model, there are two different variables, which are related to the type of dwelling (namely detached and semi-detached house). This is explained by the structure of the three indicators, which – although similar – present certain differences. In particular, the difference stems from the fact that both NEPI and modified NEPI take into consideration not only the theoretically required energy expenses but also the real ones (based on the HE045 variable of the HBS). On the other hand, the modified LIHC indicator is based solely on the theoretically required energy expenses.

Finally, it is worth commenting on the signs of the explanatory variables within the models. Except for two variables, all exhibit the anticipated signs. An unexpected sign is consistently observed across all models in the presence of kids and, for the NEPI and modified NEPI models, in the case of tenants. Upon closer examination of the dataset, it becomes apparent that the negative sign for the "Kids<4 years old" variable can be explained by the significantly higher mean income of households with children, amounting to approximately 19%. As regards the "Tenant-market rent" variable, the negative sign is ascribed to the fact that tenants live in smaller houses (by approximately 16 m^2) that are relatively newer.

3.3.3 Predicting EP households using MLA

Machine learning (ML) is a subset of artificial intelligence (AI). Machine learning algorithms (MLA) can be constructed and trained using sample data, enabling them to make predictions that excel in identifying intricate patterns within extensive datasets. Despite the occasional drawback of operating as "black boxes", ML models are widely embraced for their effectiveness and are popular especially in addressing complex tasks like image recognition, fraud detection, and medical diagnosis (Spandagos et al., 2023). So far, the application of MLA for diagnosing EP is currently limited (López-Vargas et al., 2022; Spandagos et al., 2023). However, there is a growing trend toward such initiatives (Dalla Longa et al., 2021; Mukelabai et al., 2023; Rajić et al., 2020; Spandagos et al., 2023; van Hove et al., 2022). For a more detailed analysis regarding the key challenges to and benefits from using ML in EP applications can be found in (Deloitte LLP, 2020).

---

[4] The values are as follows: 1: Before 1946; 2: 1946-1960; 3: 1961-1980; 4: 1981-1995; 5: 1996-2005; 6: 2006-2011; 7: 2012 and later

The initial and paramount phase in strategies aimed at alleviating EP involves identifying and supporting households unable to meet their energy needs. Recent research efforts at the MLA-EP interface, especially those conducted in Europe, are based on data collected via surveys, e.g. EU SILC (Spandagos et al., 2023), national datasets with socioeconomic and other data (Dalla Longa et al., 2021) or social surveys conducted in the context of research projects (van Hove et al., 2022). The results indicate that utilising MLAs can provide a clear visualisation of the mechanisms used to determine the classification of EP. This can help in the development of effective EP alleviation schemes and assist policymakers in establishing more precise thresholds for the allocation of assistance. However, the collection of information through questionnaire surveys has significant disadvantages (high cost, time-consuming procedure, inability to cover the whole population of interest). Hence, a framework enabling policymakers to pinpoint such households using objective and readily available data, eliminating the necessity for questionnaire surveys, proves notably advantageous. Such a framework would facilitate the efficient identification of EP households, without relying on self-reported data.

Considering the aforementioned observations, REVERTER's methodology aimed to minimise the number of variables, easily retrievable from relevant government agencies, without resorting to social surveys. Specifically, for applying the MLA process, the chosen dependent variable was the modified LIHC EP index that yielded optimal results in multivariate analysis. Explanatory variables included the house's construction year (directly correlated with its energy class), dwelling size (in square meters and number of rooms), and five socio-economic factors: income, household size, and the presence of young children, elderly individuals, and unemployed members. It is mentioned that (van Hove et al., 2022) also found that income, household size and floor area are universal predictors of EP. Data on socioeconomic variables can be easily obtained, in Greece, from the tax returns submitted by households every year. Also, the combination of tax returns and building census data allows for detailed dwelling information beyond age and room count.

The procedure unfolded as follows:

- The HBS dataset was initially divided into training (70%) and test (30%) sets, utilising a random but proportionally aligned method to ensure consistency in energy-poor proportions across both samples.
- Multiple MLAs, including logistic regression as the base model, neural networks, k-Nearest Neighbors, Support Vector Classifier, and Random Forests, were trained.
- Test results indicated that the Random Forests model outperformed others in classification accuracy. For brevity, the outcomes of the Random Forests model are exclusively presented here.
- The trained model was saved, and subsequently, its predictive power was tested using data from the social survey conducted in the Greek pilot study.

Random Forest (RF) is a robust technique in supervised machine learning, constructing an ensemble of multiple decision tree algorithms and combining them to produce accurate and stable predictions, particularly in classification problems. This method has gained popularity due to its capability to deliver highly precise predictions, making it a valuable tool in Energy Poverty (EP) applications as well (Spandagos et al., 2023). A comprehensive explanation of the algorithm's intricacies is beyond the scope of this document but can be explored in detail in the work of (Biau & Scornet, 2016) for regression and classification frameworks.

The overall accuracy of the model is 95%. According to the confusion matrix (Figure 49), around 87% of EP households and 97% of non-EP households of the test sample have been successfully classified by the RF algorithm. On the other hand, 13% of EP households were unsuccessfully classified as non-EP.

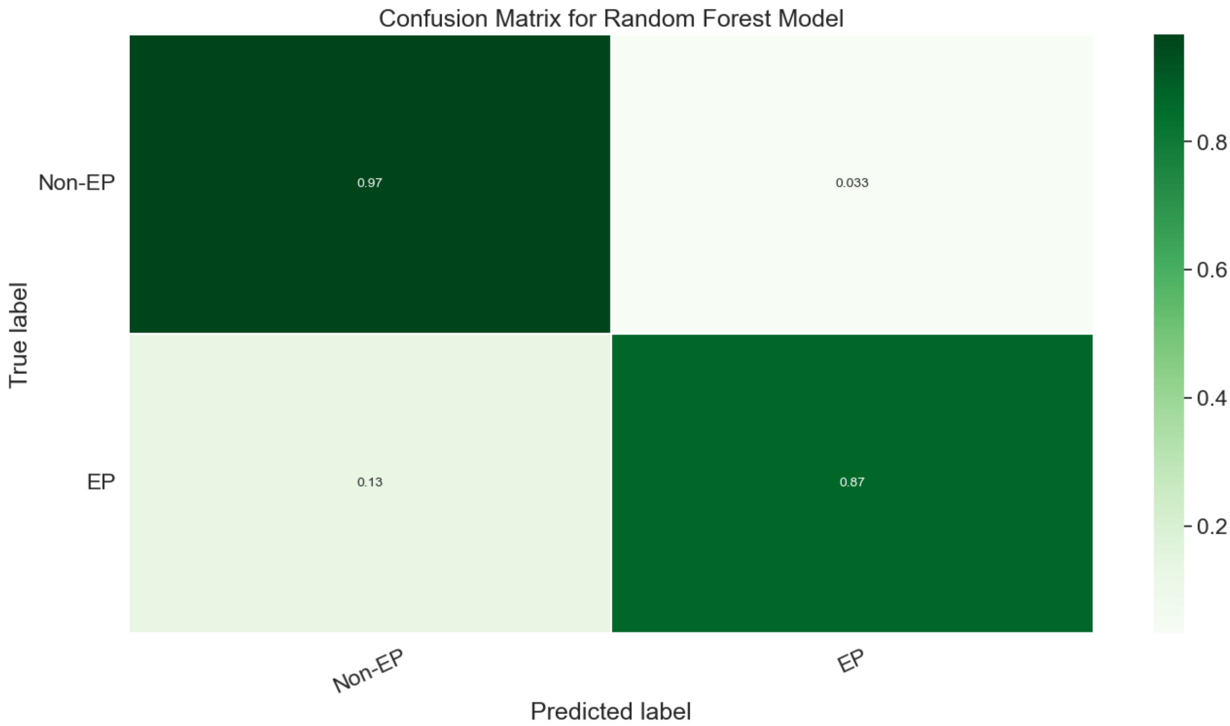


Figure 49. The confusion matrix for the RF model – test sample

As shown in Figure 50, the most important variable from a classification perspective is the income o the household followed (in terms of importance) by the total number of household members, the presence of unemployed household members and the size of the dwelling (almost equally important). The year of construction and the number of rooms are less important, and the effect of the presence of kids and elderly people plays a minor role.

As regards the verification test, the results showed that the overall accuracy of the RF model using the external sample (i.e., the social survey dataset) was reduced at 89%. Specifically, as illustrated in Figure 51, around 71% of EP households and 98% of non-EP households of the social survey sample have been successfully identified by the RF algorithm, while 29% of EP households were unsuccessfully classified as non-EP.

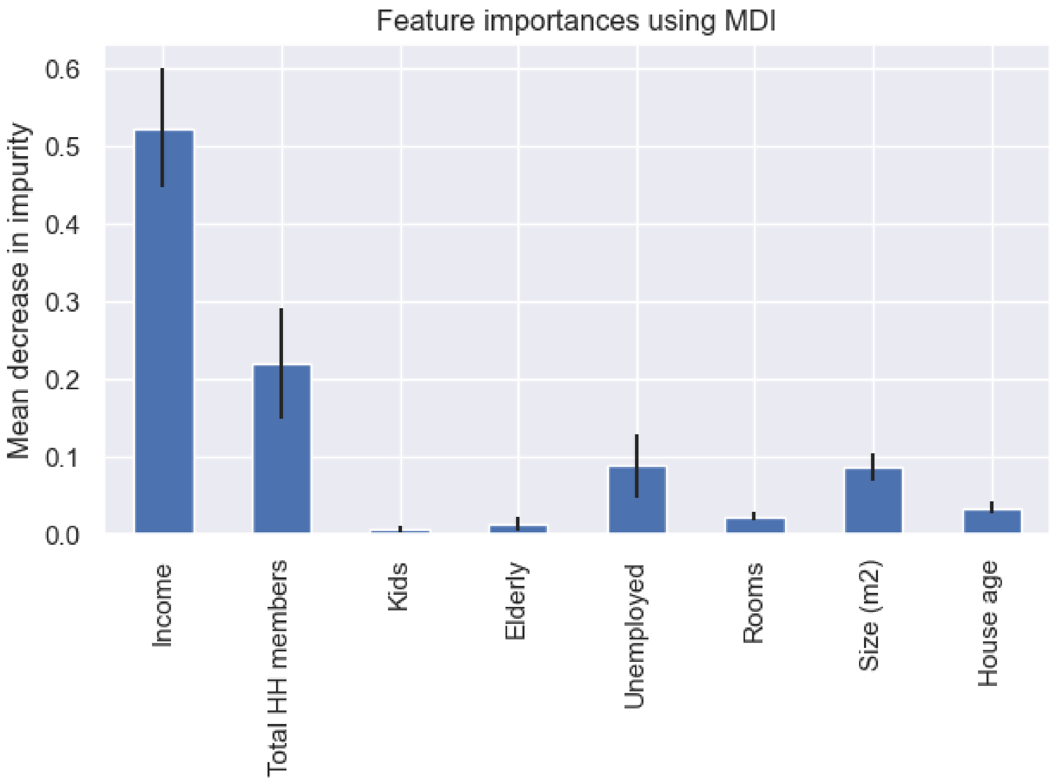


Figure 50. Relative importance of explanatory variables in predicting energy poverty

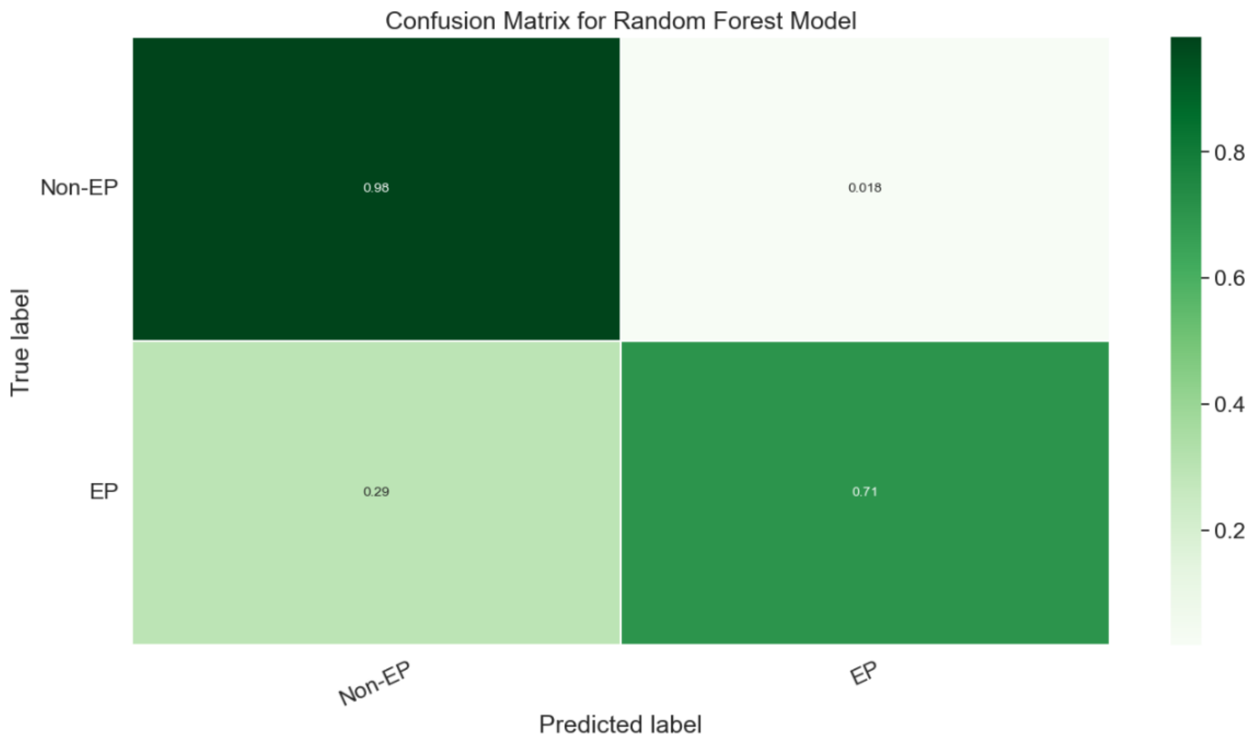


Figure 51. The confusion matrix for the RF model – social survey sample

The findings of the RF model are encouraging. It is proved that using a small number of variables it is possible to identify energy-poor households with a fairly high degree of accuracy. It should be noted, however, that the ML model was trained and applied in a specific area in terms of climatic conditions and with relatively uniform housing characteristics. It is therefore an open question whether it is feasible to successfully train a ML model with a limited number of variables (including for example only heating/cooling degree days as additional variables) on a larger geographical scale, for example at country level.

3.4 A simplified approach based on the “worst first” principle

In the previous section, three state-of-the-art approaches were employed to analyse and predict EP conditions in the Athens Urban Area pilot. The results indicate that these approaches can improve, to a significant extent in some cases, assessments of the magnitude, depth, and geographic distribution of the problem. Consequently, they can lead to the formulation of more effective policies for addressing EP.

However, these methods have disadvantages, such as the need for a significant volume of data and scientific expertise of the personnel responsible for monitoring the phenomenon of EP. It is, therefore, a critical question whether it is feasible to implement a methodology that is simple, fast, and requires minimal data, capable of identifying energy-poor households and compatible with the “worst first” principle.

As mentioned in the results of T2.1, the EP indicator that seems to be more directly related to the “worst first” principle is the “Low Income Low Energy Efficiency – LILEE” indicator of the UK. Nevertheless, this indicator, like the NEPI, modified NEPI, and modified LIHC indicators applied in the Athens Urban Area pilot, needs the estimation of the required energy expenses (and actual expenses in some indicators). The calculation of theoretically required energy expenses, especially if high accuracy is sought, is also a time-consuming and data-demanding process.

In an attempt to address these difficulties, the application of a simplified form of the LILEE indicator **(“simplified LILEE”**) was examined. Based on this proposed simplified indicator, a household is considered energy poor if its income is below 60% of the median income and if it resides in a low-energy class home. For the case of the Athens Urban Area pilot, in which the indicator was examined due to the availability of data, homes built before 1980 were considered “low-energy class”, i.e., before the implementation of the first insulation regulation.

More specifically, to estimate this indicator by the HBS data, the following process was followed:

- The three first age classes of DS018 (Year of construction) variable, i.e., houses built before 1980, were selected.
- The equivalised income was estimated by the HH099 (Net income) and HB062 (Equivalent size - modified OECD scale) variables
- Ten different income classes were created using the median national income per year, as follows:
    - Income class 1 - below 20% of the national median income
    - Income class 2 - between 20% and 40% of the national median income
    - Income class 3 - between 40% and 60% of the national median income

- Income class 4 - between 60% and 80% of the national median income
- Income class 5 - between 80% and 100% of the national median income
- Income class 6 - between 100% and 120% of the national median income
- Income class 7 - between 120% and 140% of the national median income
- Income class 8 - between 140% and 160% of the national median income
- Income class 9 - between 160% and 180% of the national median income
- Income class 10 - over 180% of the national median income

- The three first income classes, i.e., households with income less than 60% of the national median income, were selected,

By applying these two criteria and in the context of the "worst first" principle, **6.3%** of households in the Athens Urban Area pilot are considered energy poor. The corresponding rates for the expenditure-based indicators range from about **10%** (for the NEPI and modified NEPI) to **22%** (for the modified LIHC). To explore the effectiveness of the indicator in identifying energy-poor households, the other three indicators were calculated in this sub-sample of the Athens Urban Area population. According to the results, the percentage of energy-poor households is **78.5%** for the **NEPI**, **81.1%** for the **modified NEPI**, and **97.2%** for the **modified LIHC**. Hence, it can be contended that employing this simplified methodology allows for the identification of the vast majority of energy-poor households residing in the least energy-efficient homes.

In addition to its simplicity and effectiveness, the simplified LILEE indicator offers a tool for analysing various policy scenarios to investigate the extent of energy poverty for individuals residing in energy-inefficient homes. For example, incorporating individuals with incomes below 80% of the national median income leads to a **126%** increase in energy poverty, namely, from **6.3%** to **14.3%**.

Yet, the main limitation in the use of this indicator, at present, is that EU SILC survey does not include information on the age (or, if known, the energy class) of residences, and the HBS is not carried out on an annual basis in all EU countries. Also, it is not standard practice to provide information on age of residence nor for the HBS.

To examine the relationship between the modified LILEE and commonly referred drivers using binary logistic regression. As far as the overall performance of the best-fit model is concerned, the Pseudo R^2 is 74.1%, the sensitivity (i.e., the percentage of energy-poor households accurately identified as such), is about 76%, and the overall accuracy, about 97.5%.

The explanatory variables are related to both household and house characteristics, as follows:

- household income (HH income, continuous variable - HH099 in HBS),
- total number of household members (HH total members; integer variable – HB05 in HBS),
- presence of kids less than 4 years old (Kids <4 years old; binary variable: 1 if there are kids less than 4 years old, 0 otherwise),
- presence of unemployed household members (Unemployed members; binary variable: 1 if there are unemployed household members, 0 otherwise),
- year of construction of the house (Year of construction – integer variable[5] – DS018 in HBS),
- detached house (Detached house; binary variable: 1 for detached houses, 0 otherwise),

[5] The values are as follows: 1: Before 1946; 2: 1946-1960; 3: 1961-1980; 4: 1981-1995; 5: 1996-2005; 6: 2006-2011; 7: 2012 and later

- semi-detached house (Semi-detached house; binary variable: 1 for semi-detached houses, 0 otherwise),
- apartment in a building with less than 10 dwellings (Apartment<10: binary variable: 1 for apartments in buildings with less than 10 dwellings, 0 otherwise).

According to the binary logistic model, households with higher income and children under 4 years old, living in newer detached or semi-detached houses or apartments in buildings with less than 10 dwellings, are less likely to experience energy poverty. In contrast, households with a larger number of members and with unemployed members are more likely to be energy poor, according to the modified LILEE indicator (Table 15).

Table 15. Binary logistic regression results – modified LILEE

Variables	Coef.	Odds Ratio
HH income	-0.890*** (0.0472)	0.411*** (0.0194)
HH total members	2.600*** (0.166)	13.46*** (2.229)
Kids <4 years old	-1.959*** (0.542)	0.141*** (0.0764)
Unemployed members	0.533** (0.222)	1.703** (0.379)
Year of construction	-2.230*** (0.156)	0.108*** (0.0167)
Detached house	-1.339*** (0.300)	0.262*** (0.0786)
Semi-detached house	-1.008*** (0.329)	0.365*** (0.120)
Apartment <10	-0.524** (0.216)	0.592** (0.128)
Constant	9.189*** (0.635)	9,789*** (6,220)
Observations: 6,645	**Log likelihood: -408.2696**	**Pseudo R^2: 0.7411**

Std. Err. in parentheses; *** p<0.01, ** p<0.05, * p<0.1

4 Assessment of vulnerable consumers' capacity needs

4.1 Lessons learned for the Brezovo Pilot

Information was collected between May 18th and June 29th, 2023, via an online surveying platform and face-to face interviews. The target group was households residing in Municipality of Brezovo, and only individuals 18 years of age or older could participate in the survey. In total, 350 surveys were collected (online and face to face), from which 300 were validated as correct and included in the final dataset.

The main type of residential buildings in Municipality of Brezovo are detached houses and there are a few multi-family buildings in the region. More than a half of the respondents live in detached houses with two levels and 35% live in detached houses on one level. The buildings are very old, as the largest share of the existing residential building stock was created before 1949. After 2000, with the entry into force of modern and highly demanding normative documents for energy efficiency (EE), only 3% of the residential buildings were put into operation. Most of the dwellings (i.e., 94%) are privately owned without financial obligations. The analysis shows how the household members characteristics affect the annual energy costs - households with children less than 5 years old and disabled spent more money to meet their energy needs, but pensioners and unemployed spend less for energy.

Regarding the heating source, most of the respondents have indicated that they are heated with air conditioners, followed by heating with firewood. The air conditioners are preferred in the last years because of the increased demand of cooling, as well as the relatively low electricity prices. Still, 29% of those who are using air conditioners as primary heating source have additional heating sources as wood/pellets stoves, electrical devices or open firewood. Also, those who are finding it very difficult to live on current income rely mainly on individual firewood/pellet stoves, air conditioners, and open fireplaces. That is, they most probably heat only part of their homes and use (as far as the open fireplaces and firewood/pellet stoves are concerned) heating systems that degrade indoor air quality. Still, households indicated that they reach the comfort indoor temperature, and they are not deprived of heating, but it is common to restrict other necessary products or services or basic needs in order to be able to pay energy bills. Specifically, 17% of the households are unable to keep home adequately warm in the winter or cool in the summer, and 16% have condensation on windows and walls during winter. However, there are only 2% indicated arrears in the energy bills over the last 12 months and only 1% stated that have electricity or heating suspension due to non-payment of the bills.

Regarding the electricity-related awareness and behavioural issues, most of the respondents stated that they compare electricity consumption with previous years and read the consumption in the electricity bill, still some of them don't understand the charges. Only 11% often check the electricity meter reading, which means that further educational actions should be focused on energy monitoring in the households.

Regarding the implemented EE measures, most of the households have implemented new energy efficient windows and doors, but only 40% have wall/ceiling insulation. Most of the have also installed energy-saving lamps and new energy efficient appliances. As far as RES installations are concerned, only 4% of the households have installed solar water heater. Also, only 3% indicated that they had new heating or cooling sources, but this may be due to deep-seated habits of using wood stoves and reluctance to change habits.

As mentioned before, it should be noted here that until recently, Brezovo was not priority in the programmes for financing energy saving measures. According to the national programme for energy renovation of homes, priority was mainly given to multi-family residential buildings, while single-family houses prevail in Brezovo. Also, the environmental protection programme, which relied on the replacement of heating sources with modern low-emission ones, was only for large cities. The programme for the introduction of RES in households has only recently been opened, and no real activities for the installation of photovoltaic or solar collectors for hot water can be reported yet. This is why almost all the respondents haven't participated in any subsidy programmes for energy efficiency.

Regarding the reasons for not applying for financing programmes for energy saving measures, more than half of the households responded that they don't know about any programmes. When asked if they would be willing to participate in such programmes in the future, 67% answered positively, but a quarter answered that they would not participate. This means that more information campaigns should be focused among the population. It also turns out that the concerns of excessive bureaucracy and administrative obstacles in the participation and implementation of energy efficiency measures under financing programmes is not a small problem.

Based on the above conclusions, the following actions to address energy poverty in the area of Brezovo are urgently needed and REVERTER's efforts should be focused on supporting the municipality in:

- Education and awareness campaigns: Raise awareness campaigns about energy saving and energy practices within the community should be considered. They should be conducted dedicated workshops, seminars, and outreach campaigns to educate residents on how to reduce energy bills and improve their comfort.
- Energy efficiency programmes at local level: Implementation of energy efficiency programmes that help residents reduce their energy consumption. This can include energy-efficient appliance incentives, and energy education initiatives.
- Promotion of Renewable Energy Sources: Promotion of the use of renewable energy sources such as solar panels for hot water or PVs for self-electricity production.
- Access to financial support: Familiarization and connection of residents with financial assistance programmes, grants, and subsidies that can help them afford energy-efficient renovations and renewable energy installations.
- Affordable energy and social services: Collaboration with local energy providers, NGOs, civil social organisation to develop affordable energy and social services for low-income households.

4.2 Lessons learned for the Athens Urban Area Pilot

Information was collected between May 25th and June 30th, 2023 via an online surveying platform. The target group was households residing in Athens Urban Area (also known as Greater Athens), and only individuals 18 years of age or older could participate in the survey. As the survey mainly targeted vulnerable households, the questionnaire was communicated through the list of EKPIZO members living in the area of interest (approximately 2,700 people) and the website and social networks of EKPIZO, municipalities and other organisations (external collaborators, journalists, consumer associations, etc.) who participate in the project efforts. In total, 754 people followed the survey link they received from either a personal email or were informed via websites and social networks, and 496 people finished the survey.

About half of the households live in houses built before 1980, when the first building insulation regulation was adopted, and only a small percentage of houses have been built according to modern insulation regulations or have undergone radical energy renovation. It is therefore not surprising that, based on the data from the Energy Performance Certificates[6], more than 70% of the buildings belong to the three lowest Energy Performance Rating Classes E, F and G.

The old building stock, combined with the economic situation of households and the increase in energy prices from mid-2021, have exacerbated the problems of EP, especially among low-income households. Although the proportion of EP households varies depending on the indicator used (as mentioned, each indicator captures different aspects of the problem), the evidence is worrying (but comparable to the EP rate estimated by the EU SILC survey for low-income households). According to the consensual EP indicators studied:

- About half of households claim inability to keep their houses adequately warm or cool. For instance, about two-thirds of the participants said that the ideal indoor temperature is between 18-21^{o}C, however, less than 40% can heat their home to this temperature. It should be noted that the inability to keep home adequately warm indicator is significantly higher than the national indicator (i.e., 18.7%) in 2022.
- One-third of the households report condensation on windows and walls during winter.
- About one-fifth of the households report arrears on their energy bills and about 5% said that their electricity/gas supply was disconnected during the last 12 months. As mentioned, these percentages are relatively low and are attributed to the emergency energy affordability measures implemented by the Greek government to protect domestic consumers from the effects of the global energy crisis.
- About one-third of the households report health issues related to inadequate heating and/or the presence of high moisture in the house. The percentage of households reporting health problems due to insufficient heating for a house temperature of 15-18^{o}C is twice as high as the corresponding percentage for a house temperature of 18-21^{o}C, while the percentage for a house temperature below 15^{o}C is about four times higher.
- About one-sixth of the households are classified as energy poor according to the composite EP measure developed.
- About 80% of the households have restricted the use of electricity, more than 75% the use of heating, and about 50% the use of DHW to be able to pay for energy use during the last

[6] https://bpes.ypeka.gr/

12 months. Furthermore, more than half report cutbacks on food purchases, and 65% on transportation. It should be highlighted that although they cut spending on food, about one-third of the households still live in thermally uncomfortable homes, 22% face condensation/mould problems and more than 16% are in arrears on their energy bills.

Moreover, according to the expenditure-based indicators:

- About 35.7% of the households spend more than 10% of their net income on energy services.
- About 10% of the households spend on energy bills more than twice the national median as a share of (equivalised) energy expenditure compared to (equivalised) disposable income, and 7% have absolute (equivalised) energy expenditure below half the national median.
- About 5% of the households face high energy poverty risk due to low income and high energy costs (LIHC modified indicator). If those households with medium income risk but high energy cost risk and high risk due to low income and medium energy cost risk are taken also into account, the total percentage of energy vulnerable households is 19.2%.
- About 20% of the households are low-income households living in very low energy efficiency homes (LILEE modified indicator). This percentage increases to about 36%, if households with medium risk due to low income who live in very low energy efficiency and households with high risk due to low income who live in low energy efficiency homes are taken into account.

In all consensual and expenditure-based indicators, there is a negative trend between income and EP that is the average percentage of energy poor households decreases with income.

Therefore, there is a significant percentage of very low or low energy efficiency buildings, and a noticeable share of households at risk of energy poverty that could be alleviated through energy efficiency upgrades to their homes. However, the survey highlighted several barriers in this direction.

The most important barrier is the financial one that is the inability of households to invest in high upfront cost measures. On average, households claim that the ratio of total expenditure to net income is 86.8% (more than 50% of the households claim that they spend more than 70% of their available income to cover their expenditure needs). As a result, almost half of the households are struggling to cope with current income, 33.1% can make ends meet on current income, and only 10.5% live comfortably. More importantly, all households with a net income below €680 and about 75-80% of the households with an income between €680 and €1,250, i.e., the most vulnerable ones, say that they find it difficult to make ends meet. These households are therefore unable to cover the cost of renovation work from their own resources. At the same time, because of their low income, they are faced with a further financial barrier, namely the limited access to bank loans (mentioned by around 45% of the sample who have not participated in energy efficiency subsidy schemes). Nevertheless, about 80% of the households said they would be willing to upgrade their home if they were able to repay the cost of the work in instalments but 12% said that they couldn't give anything due to financial inability. Of those who agreed to pay, about 30% would be willing to give up to €60 per month, 33.5% would pay between €60 and €100 per month, 20% would pay between €100 and €200, and about 10% over €200 per month. These amounts correspond to a loan of €10,000 or less (based on current financing programmes for energy upgrades, a loan of €10,000 with a fixed interest rate of 8.75% and repayment period of 96 months has a monthly instalment of about €145). This barrier can be removed through better designed subsidy schemes on the part of the state or through Public Private Partnership arrangements, where the public sector uses private companies, like the Energy Service Company (ESCO), to stimulate private sector investments and promote energy efficiency.

Government intervention is also needed to remove three other barriers identified during the survey. The first is a regulatory barrier, namely the complex administrative process, excessive paperwork, lengthy approval procedures, and bureaucratic hurdles (mentioned by more than 50% of the sample) required to enrol a household into existing energy efficiency subsidy programmes. The second one is a known decision-making barrier, i.e., split incentives between tenants and landlords (mentioned by 26% of the households). The third barrier is an organisational barrier related to ownership status of the house (reported by about 16% of the respondents). This is a relatively common problem for vulnerable households, as they often live in a house that they have inherited from their family but do not have full ownership, as they cannot afford to pay inheritance taxes or other financial obligations that may exist.

Finally, two informative/behavioural barriers were raised, namely the perceived lack of personal benefit from energy retrofits and the lack of awareness about such subsidy programmes (mentioned by about 25% and 20% of the participants, respectively).

The last two barriers, and to a certain extent the problem of bureaucracy for enrolment in a subsidy scheme, can be addressed during the pilot operation of the Greek OSS in the area of interest, in combination with other actions that will take place in the context of the project (e.g., local engaging events, information materials, awareness campaigns, etc.). All the findings of the survey, in terms of the characteristics of the dwellings and households in the area, the characteristics of energy poverty and the main barriers, will be considered when designing the Greek roadmaps and developing policy recommendations.

4.3 Lessons learned for the Riga Pilot

The survey results show that most of the households participated in this survey live in the buildings built in the soviet time era (about 60%) and another 25% live in buildings built before 1940. These buildings have been built before energy efficiency was considered as intrinsic part of building technical design. Moreover, the technical systems of these buildings, in the majority of the cases, are in very poor condition and in need of concrete system renovation. The envelope of these buildings in some cases has significantly decayed and in some cases poses a safety risk to the inhabitants of the building themselves.

The old building stock, combined with the economic situation of households and the increase in energy prices, have exacerbated the problems of energy poverty, especially among low-income households. Although the proportion of energy vulnerable households varies depending on the indicator used, the evidence is worrying. According to the consensual EP indicators studied:

- There is a discrepancy between households, who mention that apartment indoor temperature during winter is adequate and the stated indoor temperature in heating season. About 40% of the respondents noted, that in winter the indoor temperature in apartment is not satisfactory, however by comparing this result with self-reported indoor temperatures, 78.4% report indoor temperature above 18°C during winter. This suggests that there are additional factors, which may influence perceived comfort level in winter – draught, uneven temperature distribution in the apartment, low temperature on external wall surfaces, dampness, etc.

- About 41.8% of surveyed households claim inability to keep their houses adequately warm in winter. These percentages exceed 49.3% in households with a monthly income of less than around €900.
- Around 22% of the households report condensation on windows and walls during winter.
- About one-fifth of the households (21.6%) report health issues related to inadequate heating and/or the presence of high moisture in the house. Low-income households appear more vulnerable to these problems. For example, the percentages are 33.3% for households with a monthly income below €900.
- Only about 4% report arrears on their energy bills and none of the respondents said that their electricity/gas supply was disconnected during the last 12 months. These percentages are relatively low and maintain low also for households with a monthly income of less than around €900 (also 4%).
- About 42% of the households have restricted the use of electricity, more than 19% the use of heating, and about 38% the use of DHW to be able to pay for energy use during the last 12 months. Furthermore, one-third report cutbacks on food purchases, and 23% on transportation.

Moreover, according to the expenditure-based indicators:

- About 37.0% of the households spend more than 10% of their net income on energy services.
- The 'local' 2M and M/2 indicators are equal to 9.3% and 10.1%, respectively.
- A composite EP measure was also developed by the consensual indicators. According to this indicator, the energy poor households (i.e., those having a value above 0.5) are 9.2%. Households with a monthly income below €900 are classified as energy poor at 14.7%.

The survey highlighted several barriers in household ability to apply for energy efficiency grants. The most important barrier is the inability of different apartment owners to agree on participation in the subsidy programme for building renovation, followed by the reluctance to deal with bureaucracy involved managing the building renovation and subsidy programme. Interestingly very low number of participants mentioned that the financial burden may be too high in the case of renovation. This may be due to the fact, that heating costs are relatively high and there is no real option not to heat a home in case of multifamily buildings. The heating system design of most multifamily buildings built in soviet times does not allow the possibility to heat separate apartments of the building – if heat energy is supplied to a multifamily building, then the heat energy is also distributed to all apartments. The aim of the survey was also to explore if myths related to building renovation have any substantial weight in decision-making process. The results showed that the myths of building renovation do not play a significant role in decision-making process – only as a fourth most important reason for not renovating a building, the possibility of accelerated mould growth was mentioned.

The survey showed that in buildings, which were built after 2010, the total reported heating costs were the lowest. This shows that it is possible to reduce building energy consumption, if the building envelope corresponds to the latest national building code regulations. One-stop shops can have a major influence on building renovation by helping to disseminate the benefits of building renovation and help to persuade those building apartment owners who are opposed to building renovation. The two most leading causes for not renovating the building are – (1) inability of apartment owners to agree on renovation and (2) reluctance to deal with bureaucracy related to application for a grant.

4.4 Lessons learned for the Coimbra Pilot

The decades with the highest percentage of buildings constructed in Portugal were 1961–1980 (~30%) and 1981-1990 (~16%) [INE, 2023]. The decades 1961–1980, period with highest building construction growth, are typically considered as a period with buildings with a poor energy performance because the first thermal building code was enacted in 1990 (Monzón-Chavarrías et al., 2021). Therefore, these buildings do not have any thermal insulation. The building characteristics of Coimbra region are influenced by its historical and cultural heritage, as well as its geographical and climatic conditions. Regarding the type of construction, most of the Portuguese multi-family buildings built between 1971 and 1980 have reinforced concrete structures (54.15%), rendered and painted façades (88%), and pitched roofs with ceramic tiles (93.4%). Most of the multi-family buildings built between 1971 and 1980 in Portugal have 2 floors (33.7%) or 3 floors (19.4%), and the dwellings have a useful floor area of 70–99 m2 (19.9%) Windows occupy 17–23% of the façades. The Pilot has 4 floors and 65 m^2 of useful floor area per dwelling. The results of the social survey are in line with the information available from statistics and literature: most respondents live in houses that were built between 1960 and 2010, built on concrete structures and low insulation (75%). The main type of the buildings are apartments (67%) followed by detached houses (24%) and semidetached houses represent 9%. Most buildings have 2 or 3 rooms (72%) and around 20% of the houses have more than 3 rooms. Regarding the envelope of the houses, in particular the openings, 60% have double glazed windows and 9% triple glazed, but only 47% have frames with thermal cut. For the blinders and shutters, 92% of the households have internal (16%) or external shutters (77%). Only 7,6% do not have any shutters.

In relation to the ownership status of dwellings, only 26% of respondents own their house without financial obligations, among which, 10 respondents indicated their decision must be validated by a condominium. In relation to climatization and indoor comfort felt by the respondents, the radiant floor and central system are the solutions that seem to provide the best comfort. It is also interesting to see that those households indicating less comfort issues at home have solar PV and solar thermal installed. Nevertheless, the percentage of households owning solar systems is as low as 8,4% and those owning radiant floor is 1,3%. Heating is mainly provided by electricity (55%), followed by natural gas and biomass, with 15,3% share each. The most common heating system is local and portable systems based on heat recovery fireplaces and open fireplaces (64%), electric resistance (18%) and heat pumps (13%). Condensing boilers only share 5,3%.

While in Portugal air conditioning ownership rate is on average 21%, according to recent market surveys, in our sample, 43% of households indicate to have some kind of air conditioning system, mostly local systems. Among those, about 60% have one equipment for mostly one room, central systems are only available in 17% of the households and 23,4% use a portable system for meeting their cooling needs (portable ACs, portable heat pumps, etc.).

The analysis carried out do not allow us to make robust conclusions about the main factors impacting the energy costs, beyond the geographical location and climatic zone. Comparing the self-declared comfort between the different socio-economic households, average income, expenses and energy bill per month within the same region, it is not possible to establish any co-relation between the level of income and the self-declared comfort. Those in the highest income range also represent the highest percentage saying the house is extremely hot and/or cold for this climate. Paradoxically, the lower income households, up to 900 € per month, are among those who self-declared *most comfortable except one week per season and adequately prepared for the climate.* A possible justification for this phenomenon, based on the interviews carried out in social houses, is the embarrassment and the fear of losing their home. These are mostly elderly living with very low pensions who are used to living with low temperatures inside.

Based on the amount declared for winter energy bill and monthly incomes, if we analyse the all sample, in 88% of respondents' the energy bill represents less than 10% of their income, and 12% of surveyed households spend more than 10% of their net income on energy services. If we look only at the lower income households (those with net income <800€ per month), 29% of surveyed households spend more than 10% of their net income on energy services. Among these, more than 95% indicate they have struggled to pay the bills.

Furthermore, when asked about arrears in energy bills, 85% of respondents declared they have never been in arrears. A very small share of people (9%) indicate they rarely are in arrears and less than 4% assume they have already been in arrears for economic constraints. Crossing arrears and the number of children within the households (any age), it seems there is no positive correlation, on the contrary, what seems to be logical as a family always protects children from vulnerabilities. It is however possible to infer that single parents face higher constraints with paying energy bills. If we look closer at the group single & one child and the monthly income, it is possible to understand that those parents living with the minimum salary (between 600€-900€ per month) are the ones more often in arrears.

To identify the available support mechanisms, both local and national level, and characterize the user´s awareness of existing support programmes and respondents were given with 3 potential measures, social tariff, support to improve energy efficiency and one-stop shops, and free text was admitted. Regarding social energy tariffs, about 10% are covered by a social tariff and 50% are not eligible. The remaining, do not know about it and did not apply. Since social tariff is attributed automatically, it can be assumed that 40% of respondents are not eligible and are not aware. When we look at the National or Local programmes to support energy efficiency, also around 10% applied and got support (9.6%), and 55% did not apply. Those that are not aware of such programmes are about 23%, and 9% were not eligible. Awareness about one stop shop seems to be missing and or not popular as 50% replied do not know and about 42% did not apply. Other support programmes identified by a few respondents are renewable energy communities, incentives for solar PVs and solar thermal and “1º direito in Matosinhos” (the only support program for energy renovations that at least one respondent was aware of).

The driver to apply to support schemes to improve energy efficiency seems to be related with house tenure: households that own the property and do not have bank loans apply more often for support than those most in need. This can be an indication of the shortage of budgets, and also about the education level, but provides an indication to policy makers about the design of the subsidy schemes: upfront costs cannot be covered by the lowest income households, and the application process needs to be simple if the target is lower income.

Those that did not apply for support programmes and initiatives had the chance to indicate the three main reasons why, from a list of 10 options, and were asked to rank the three reasons according to the order of importance. The most voted reasons were excessive bureaucracy, uncertainty about what to do in the house and the complexity of the process, followed by the low share of the subsidy provided and uncertainty about the real impact on the energy costs.

In a potential scenario of carrying out improvements in their homes, households were asked how much money they could give on a monthly basis to repay the costs of the works. Very few households are willing to pay a reasonable amount per month for carrying renovations. There were 26 no replies (8.7%), and 66 households (22%) who would not pay anything as they indicated zero euros (which was not even included in the options provided). 18 households indicate other amounts and provide interesting replies: depends on the upfront costs; the house is rented so no keenness on spending money on retrofits; a retired indicated the amount received per month does not allow other expenses than basics; others indicated the amount 500, 1000, 5000 at once, but depending on the payback (5 years payback time was indicated by one respondent.

At national level, there is a need to work on developing and improving existing poverty indexes and indicators considering the several dimensions of poverty, targeted to the regions (most inner regions suffer far more), and then design tailor-made effective policies, close to real needs. The pandemic, the rising inflation rate, and the high migration rates intensified inequalities and increased the number of families living with economic constraints. Furthermore, in a scenario of a huge housing crisis in the larger cities in Portugal, Energy Poverty is going far beyond the usual definition, bringing the complexity of Poverties to the arena: energy poverty, digital poverty, education poverty, food poverty, etc. Even though environmental impacts from energy production are not the main issue in Portugal, in parallel with energy renovations of the buildings, the promotion of distributed energy generation by supporting renewable energy communities, involving all sectors and society, based on innovative/social focused business models that favour the most vulnerable, can significantly contribute to leverage the welfare of most vulnerable communities. The analysis show evidence that energy poverty is clearly related to economic poverty and geographical location. Even if care should be taken as our sample is not robust in terms of representativeness, in winter, no matter whether the benchmark used is € per person or € per square meter, those living in the more inner parts of Portugal have higher effort to pay the energy bills. Establishing regional indicators when policies are being designed for the country, seems to be logical from a social perspective of equity and justice, based on the results of our survey. The debate on regionalization in Portugal comes up time and time again, especially when there are elections, precisely because regions far from Lisbon and Porto feel disadvantaged in terms of taxation and good governance.

This orchestration of different interests at different levels is the only way possible towards the energy transition leaving no one behind. Based on the findings presented here, capacity building and education play an important role, as well as the local action and support driven by Municipalities who know well the real needs of their citizens.

Thus, in line with the European Commission's ambitious objectives, the strategies advocated should focus on:

1. Analysing existing energy rehabilitation techniques and adapting them to the region, in a process of multidisciplinary collaboration and co-creation of innovative and effective solutions in conjunction with local players and stakeholders, in a logic of non-invasive intervention and life cycle analysis, complying with the legal and normative framework defined by the regulation of the energy performance of buildings.
2. In a mild climate as in Portugal, the installation of heat pumps with a high coefficient of performance is cost-effective [RAP] compared to other heating systems, with additional benefits in terms of indoor air quality, greater comfort and consequently a reduction in the risk of respiratory diseases (Lowes et al., 2022). Although the installation of heat pumps in new buildings is conventional, replacing existing heating systems with heat pumps is not a regular practice, even though reversible heat pumps can cover heating, cooling and domestic hot water needs, with no local emissions and enormous potential for using solar energy.
3. Accelerate the implementation and promotion of passive houses and other building standards, installing solar thermal systems for heating sanitary water, as well as promoting services provided by renewable energy communities, as there is already legislation and regulation in force, the municipalities are keen on REC and are open to innovative schemes, but the implementing authorities are lagging behind in the evaluation and approvement of the projects.
4. “One-stop shops” that provide information, guidance and rehabilitation services to vulnerable households, are emerging in the market, associated with European projects, but more need to be established in association with municipalities to enrol vulnerable households in financing programmes to improve energy efficiency, health and comfort conditions in their homes, as well as to increase their interest in rehabilitation by providing access to relevant information to support decision-making from the earliest stages of the process.
5. No less important, actions aimed at promoting awareness through less formal activities involving the population and the exchange of knowledge, training and coaching in order to promote the development of skills and combat energy illiteracy, are crucial for the success of this concerted action.

5 Conclusions and recommendations

The findings of this deliverable serve as input for ongoing/future tasks of the project and as a guide and inspiration for future research and improvements in EP diagnosis. The main findings of the surveys are presented in previous sections, while an extensive analysis by pilot area is given in Annexes I and II. Therefore, this section underscores the conclusions at a broader level.

At the project level, secondary and primary data were analysed in order to determine the levels of energy poverty in each pilot area, as well as the main drivers of the problem. Specifically, we investigated to what extent the characteristics of the buildings stock and the used heating and cooling systems, the climatic conditions, the households' income and the respective energy expenditure, the households' knowledge and attitudes on energy use, the penetration of energy saving measures and the barriers of their implementation influence the energy poverty levels as well as the effectiveness of the policies implemented to tackle the problem. For instance, in Brezovo pilot, more than 60% of the households said they had not applied for a subsidised energy saving programme because they did not know it existed, while the corresponding rate in Athens Urban Area was 20%. Also, households in Athens Urban Area mentioned (by more than 50% of the sample) they are concerned about the complex administrative process, excessive paperwork, lengthy approval procedures, and bureaucratic hurdles required to enrol a household into existing energy efficiency subsidy programmes, while households in Riga identified, as the most important barrier, the inability of different apartment owners to agree on participation in the subsidy programme for building renovation. The specific characteristics identified in each pilot area, even at the cultural level, combined with the existing institutional framework and subsidised energy saving programmes will be exploited by the project partners for the finalisation of the roadmaps, the design of the OSSs, and the preparation of tailormade materials for community capacity building programmes.

As mentioned, the analysis did not only provide valuable information for the design of the next project activities in the four pilot areas. Through the analysis, valuable insights emerged that can help to address one of the most important challenges that the European Union and its Member States face in the fight against EP, namely identifying households that are in or at risk of EP and need to be assisted. The main problems currently encountered in this effort relate to the characteristics of the indicators used and their data collection framework. The main indicators currently applied to measure EP levels at European and national level (very few countries have official national indicators to measure the phenomenon) are the inability to keep the home adequately warm, the arrears on utility bills, and the total population living in a dwelling with a leaking roof, damp walls, floors or foundation, or rot in window frames or floor. Actually, these three indicators, together with the at-risk-of-poverty rate are required to be considered by the Member States when assessing the share of energy poverty in their national energy and climate plans [Article 8 of Directive 2023/1791 of 13 September 2023 on energy efficiency and amending Regulation 2023/955 (recast)].

These indicators are calculated and published annually by the EU SILC and provide a common basis for measuring and comparing EP levels within and across the Member States. These indicators, serving as a standardised metric, play a pivotal role in monitoring EP and evaluating the efficacy of policies aimed at its alleviation. However, the identification of EP households faces certain limitations. Primarily, these indicators rely on perceived EP levels, notably in the context of challenges like the inability to maintain an adequately warm home. To mitigate subjectivity concerns, alternative expenditure-based indicators have been introduced by the European Observatory on Poverty and Social Exclusion (EPOV) and its successor, the European Observatory on Energy Poverty (EPAH). Yet, these indicators are dependent on HBS data, available for select years during HBS conduction and limited to specific Member States. A more significant limitation arises from the fact that the three aforementioned indicators can only be estimated through questionnaire surveys. Consequently, EP conditions are ascertainable solely for households within the survey's sampling framework. Compounding this issue, the EU SILC lacks vital information related to EP, such as dwelling energy performance, area, and certain household characteristics.

In response to these challenges, Member States predominantly focus on identifying households at risk of EP from a financial perspective. This approach, however, represents a notable shortcoming, as it overlooks the distinction between income and fuel poverty - two distinct problems necessitating tailored policy solutions (Tovar Reaños, 2021). For instance, some Member States employ criteria from the social welfare system to define energy vulnerable households. However, this approach may lack a meaningful connection with the actual energy poverty status of individuals. This is evident in cases where recipients of the electricity social tariff, deemed eligible by social welfare criteria, may not align with the definition of energy poverty according to headline indicators, and vice versa (Sareen et al., 2020).

The divergence between income and energy poverty underscores the need for a more nuanced and comprehensive framework that encompasses both social welfare considerations and specific energy-related challenges and goes beyond pure financial metrics. At the same time, this framework should empower policymakers to identify energy-poor households using objective and readily available data, thereby reducing dependence on questionnaire surveys and self-reported indicators.

REVERTER attempted to address these challenges by using (and testing) state-of-the-art tools in EP analysis and prediction and by developing new EP indicators. Regarding the methodological tools, REVERTER used spatial representation and analysis of selected EP indicators and primary drivers (namely income and house energy efficiency risk), multivariate logistic regression models to examine the relationship between selected EP indicators and commonly referred EP drivers (including housing and sociodemographic variables), and MLAs to investigate if it is possible to identify EP households with a fairly high degree of accuracy using a small set of variables, easily retrievable from relevant government agencies, without resorting to social surveys. These methodological tools were tested only in the Athens Urban Area because suitable data were not available for the other pilots. The main strengths and weaknesses of these tools are highlighted hereinafter.

EP mapping has the capability to identify areas at highest risk of EP. As a result, the creation of local EP maps can assist local and national authorities in strategically directing interventions (e.g., the development of specific infrastructure such as the gas network) from a spatial perspective. This could ensure a coherent and holistic approach to addressing EP at the household level. By adopting EP mapping, there is also a potential to catalyse large-scale energy retrofit programmes, consequently reducing associated costs. The insights derived from these EP maps hold significant potential for guiding policymakers, enhancing the overall cost-effectiveness of EP alleviation policies and programs. On the other hand, it is a data-demanding approach, if the analysis must be conducted at neighbourhood or block level to be meaningful. For instance, in the Athens Urban Area the analysis was based on zip code aggregated data and still certain areas of the pilot remained unexplored due to lack of observations. However, state authorities and governmental agencies have access to confidential housing and socioeconomic spatial microdata (e.g., evidence from tax returns, building characteristics from censuses or databases of Building Energy Performance Certificates, etc.) that would help to create the relevant EP maps at block or even building level.

Multivariate analysis provides valuable insights into the impact of sociodemographic and housing characteristics on EP. Specifically, it elucidates the associations between EP drivers (explanatory variables) and indicators (dependent variable). Regression models serve not only to scrutinize the sign and significance of relationships but also to establish a predictive model for EP risk. This entails predicting the odds of EP risk based on the values of explanatory variables. However, this method is not without challenges. Developing a robust model necessitates meeting certain conditions. Foremost and crucially, the dataset should include information on critical parameters, and ample, representative sample sizes are essential for obtaining unbiased estimates. For example, as highlighted in Section 3.3.2, regression models for EU SILC indicators exhibited poor performance due to the omission of vital variables (omitted variables bias). Furthermore, the predictive accuracy of models may be compromised by fluctuations in the values of factors influencing the phenomenon but not accounted for in the model. For instance, changes in energy prices could escalate both real and theoretical required energy expenditures, compelling more households into energy poverty. In such cases, regression parameters would also be affected. This underscores why a pooled sample, covering a 5-year period, was employed in this study instead of constructing separate annual models. This approach ensures a more comprehensive understanding of the dynamics, mitigating the impact of short-term fluctuations and providing a more robust foundation for analysis.

Machine learning (ML), a subset of artificial intelligence, has the potential to directly enhance the identification of EP households and, thereby enabling more precise allocation of targeted assistance. Enhanced identification of EP households is posited to yield significant benefits, including potential net energy savings and emissions reductions, particularly if households consume energy at levels conducive to satisfying energy service requirements. Alternatively, improved energy services could ensue if households are currently under-consuming energy. These positive outcomes are associated with the prospect of a higher number of EP households benefiting from social assistance, contingent upon a more efficient identification process, assuming that public funds remain constant. The latter underscores the significance of carefully examining the dynamic relationship between climate policies and energy affordability, particularly regarding its potential impact on vulnerable households in countries with limited fiscal resources. More crucially, it emphasises the necessity of seamlessly integrating energy poverty into the formulation of climate policies, strategies for climate transition, and overarching climate ambitions. Additionally, predictive models based on ML algorithms can significantly reduce the time and cost required for identifying EP households. This efficiency leads to a more judicious use of existing resources. Furthermore, these models contribute to the design of more effective energy efficiency schemes by providing a deeper understanding of the factors that exert the most influence in determining whether a household is, in practice, energy poor. This heightened understanding enables the development of targeted strategies to address the root causes of EP, making interventions more precise and impactful. The findings of the ML model tested in REVERTER are encouraging. It is proved that using a small number of variables (already known in public authorities) it is possible to identify energy-poor households with a fairly high degree of accuracy. It should be noted, however, that the ML model was trained and applied in a specific area in terms of climatic conditions and with relatively uniform housing characteristics. It is therefore an open question whether it is feasible to successfully train a ML model with a limited number of variables (including for example only heating/cooling degree days as additional variables) on a larger geographical scale, for example at country level. Furthermore, ML like any other tool, confronts several challenges. The predictive efficacy of ML models is notably contingent on the quality and comprehensiveness of the underlying data and features. Similar to multivariate models, the accuracy of ML models is constrained by limited data availability. In scenarios where data is scarce, the predictive power of the model may be compromised. Another notable challenge is the potential for biases within the underlying datasets, either against specific subgroups or in failing to fully represent the broader population under consideration. This can result in unfair outcomes and misrepresentations of the actual dynamics, especially when certain groups are underrepresented or systematically excluded. Last but not least, it is essential to acknowledge the practical limitation that creating an ML model entirely free of false negatives – i.e., instances where households in EP are inaccurately classified as not in EP by the model – is not practically feasible. This inherent limitation should be considered when interpreting the results and implications of ML applications in identifying EP.

Apart from the methodological tools, REVERTER introduced alternative EP indicators, e.g., the Weighted and Simple Composite Indices, the modified NEPI, the modified LIHC and the simplified LILEE. Of broader interest are the last two indicators, namely the modified LIHC and the simplified LILEE (the Weighted and Simple Composite Indices are combinations of the widely used EU SILC's consensual indicators and the modified NEPI is a variation of the officially established EP indicator used in Greece).

The modified LIHC is a variation of the UK's LIHC indicator. The UK's LIHC indicator defines a household as EP if fails to meet two thresholds – one for income and one for energy costs – i.e., if the costs to achieve adequate energy services pushes the household below the threshold of poverty, and if the required energy costs of these households are higher than those of the median household. The threshold for low income is set at 60% of median income plus the individual household's modelled energy needs. Income is calculated on an 'after housing costs' basis (deducting mortgage, payments, rent) and equivalized to account for the household composition. The high costs threshold is the contemporary median modelled bill, representing "typical" energy requirements for households in England. As with income, modelled energy expenses are equivalised for household composition and size.

The modified LIHC indicator classifies a household as experiencing EP if its equivalised residual income falls below 60% of the equivalised median national income. This index is derived by subtracting 60% of the equivalised simulated energy costs (necessary to ensure adequate energy services to the household) from the equivalised total income of the household. The estimated energy costs are based on KENAK's (the Greek Regulation of Energy Performance of Buildings) theoretical required energy consumption. However, only 60% of the theoretical required energy consumption is considered. This adjustment accounts for the finding in Greece that real energy consumption tends to be 60% of the theoretically estimated needs.

Importantly, unlike the UK's LIHC, housing costs are not subtracted from income in this modified LIHC calculation. The analysis of the Greek pilot data and results from previous surveys reveal a notable pattern: house owners paying a mortgage are significantly under-represented in energy poverty indicators across Europe. This phenomenon is attributed to the rigorous credit checks conducted by financial institutions before granting mortgage loans. Given that this tenure group possesses sufficient available resources to access the mortgage market, they appear to be less impacted by energy poverty (Koukoufikis & Uihlein, 2022). To prevent distortions, the proposed indicator refrains from deducting even rental costs. However, it allows for the application of correction factors to the estimated residual income to account for specific household categories (e.g., single-parent families, tenants paying market-rate rent, etc.).

The suggested indicator boasts two primary advantages. Firstly, it relies solely on objective datasets that encompass the three main drivers of EP: the energy efficiency of dwellings, energy costs, and household income. Notably, it circumvents the need for collecting questionnaire data, as information on dwelling characteristics can be sourced from Building Censuses and/or databases of Building Energy Performance Certificates, while income data can be retrieved from tax authorities. On the other hand, however, the modified LIHC necessitates the calculation of theoretically required energy costs. This calculation either relies on a set of assumptions, potentially compromising result accuracy, or demands the collection of detailed dwelling data, a process that is both time- and resource-intensive. Striking a balance between these considerations is imperative for optimal results.

Under the latest UK’s Low Income Low Energy Efficiency indicator (LILEE) indicator, households are considered to be energy poor if they have a fuel poverty energy efficiency rating (FPEER) of Band D (68) or below and if the disposable income (after housing costs and energy needs) would be below the official poverty line. The FPEER needs to be calculated and is based on the UK Government’s Standard Assessment Procedure (SAP) that measures the energy performance of domestic properties. This indicator has a direct connection to the “worst first” principle and thus it is considered of great importance.

In an effort to avoid extensive calculations, REVERTER proposed a new indicator, namely the “simplified LILEE”, which is a simplified version of the UK’s LILEE. Based on the simplified LILEE, a household is considered energy poor if its income is below 60% of the median income and if it resides in a low-energy class home. For the case of the Athens Urban Area pilot, in which the indicator was examined due to the availability of data, homes built before 1980 were considered “low-energy class”, i.e., before the implementation of the first insulation regulation.

As discussed in Section 3.4, the simplified LILEE indicator is simple and effective and, most importantly, it allows for the identification energy-poor households residing in the least energy-efficient homes. In addition to its simplicity and effectiveness, the proposed indicator offers policymakers the ability to analyse various policy scenarios. The main limitation in the use of this indicator, at present, is that EU SILC survey does not include information on the age (or, if known, the energy class) of residences, and the HBS is not carried out on an annual basis in all EU countries and does not provide information on age of residence on a regular basis.

A final comment, which is of primary interest to EU officials and policymakers, concerns the data on which the calculations of the various indicators are currently based, primarily the EU SILC and HBS data. With the exception of Hungary (Menyhert, 2023), data in all countries for the EU SILC and HBS are gathered from different population samples. Additionally, HBS data is available for select years (2010, 2015, and 2020) in only a few countries, presenting challenges that include:

- The Commission recommendation (EU 2020/1563) on EP outlines specific indicators and defines particular survey variables required for their calculation. These include consensual and expenditure-based indicators which are collected separately on either the SILC or the HBS data component. Consequently, they do not allow for a joint micro-level analysis and, thus, have limited comparability.
- Existing indicators lack the direct capacity to capture buildings' energy efficiency, thereby challenging the application of the "worst first" principle.
- Essential variables, such as the year of house construction and household characteristics, are absent from either EU SILC or HBS datasets.

To address these challenges, the following measures could be considered:

- Annual Implementation of HBS: Adopting a mandatory annual implementation of the HBS, aligning it with the EU SILC schedule.
- Enriching EU SILC variables: Augmenting the EU SILC dataset with critical variables for measuring energy poverty (especially if HBS is not implemented on an annual basis). This includes incorporating variables like the year of dwelling construction, energy class certification (if any), expenditure on electricity, gas, and other fuels, as well as demographic information such as the number of unemployed or economically inactive individuals in specific age groups (e.g., number of persons aged less than or equal to 4 and number of persons aged more than or equal to 65).
- Harmonizing common variables: Facilitating the harmonisation of common variables between EU SILC and HBS to ensure direct comparability. For instance, variables like HBS HY020 and EU SILC HH095 or HH099 are not directly comparable.
- Conducting a specialised survey along with the HBS every three years so as to obtain data about the energy performance and use of the utilised energy systems and equipment for all the end-uses (space heating, space cooling, domestic hot water, cooking, lighting and electric appliances), the potential implementation of energy efficiency interventions and the energy behaviour of the households.
- Fostering EP definitions that enable the bottom-up identification of EP households, by leveraging data from government services, such as tax offices, without necessitating primary questionnaire surveys.
- Ensuring the continuous monitoring of the parameters, which affect EP aiming at the potential improvement and readjustment of the overall framework.
- Facilitating the establishment of EP observatories to monitor the evolution of the energy poverty using different metrics.

These proposed measures could enhance the robustness, comparability, and comprehensiveness of the data used for EP analysis, offering more nuanced insights for effective policymaking at the EU level.

6 References

Biau, G., & Scornet, E. (2016). A random forest guided tour. *Test*, *25*(2), 197–227. Scopus. https://doi.org/10.1007/s11749-016-0481-7

Bouzarovski, S., & Tirado Herrero, S. (2017). The energy divide: Integrating energy transitions, regional inequalities and poverty trends in the European Union. *European Urban and Regional Studies*, *24*(1), 69–86. https://doi.org/10.1177/0969776415596449

Council of European Energy Regulators. (2021). *First Analysis of the COVID-19 Pandemic's Effects on the Energy Sector—Interim report* (p. 55). CEER. https://www.ceer.eu/documents/104400/-/-/31d2aad0-f7b3-46cf-b7e9-1ef382ad2e87

Dalla Longa, F., Sweerts, B., & van der Zwaan, B. (2021). Exploring the complex origins of energy poverty in The Netherlands with machine learning. *Energy Policy*, *156*, 112373. https://doi.org/10.1016/j.enpol.2021.112373

Deloitte LLP. (2020). *Better use of data and advanced statistics / machine learning in delivering benefits to the fuel poor* (p. 82). https://assets.publishing.service.gov.uk/media/5eda318d86650c4ab64fb350/Deloitte_-_better_use_of_data_to_support_the_fuel_poor.pdf

Encinas, F., Truffello, R., Aguirre-Nuñez, C., Puig, I., Vergara-Perucich, F., Freed, C., & Rodríguez, B. (2022). Mapping Energy Poverty: How Much Impact Do Socioeconomic, Urban and Climatic Variables Have at a Territorial Scale? *Land*, *11*(9). https://doi.org/10.3390/land11091449

European Commission. (2020). Quarterly Report on European Electricity Markets with special focus on extra-EU electricity trade. *GD Energy*, *13*(2).

Eurostat. (2023a, February). *Heating and cooling degree days—Statistics*. https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Heating_and_cooling_degree_days_-_statistics

Eurostat. (2023b, February 2). *Cooling and heating degree days by NUTS 3 regions—Monthly data*. Eurostat - Statistics. https://ec.europa.eu/eurostat/databrowser/view/nrg_chddr2_m__custom_7842696/default/table?lang=en

Founda, D., & Pierros, F. (2021, February 26). *The 'new' climate of Athens—Period 1991-2020*. Kosmos. http://magazine.noa.gr/archives/4446

Grigoriou, R., Korras, I., & Papamarkou, I. (2021). *COVID-19 Impact on European Energy Market Prices—H2 2020 (July-December)*. VaasaETT. https://www.vaasaett.com/measures-taken-across-europe-and-impacts-of-the-pandemic-on-energy-prices/#dearflip-df_2069/3/

Grubesic, T. H. (2008). Zip codes and spatial analysis: Problems and prospects. *Socio-Economic Planning Sciences*, *42*(2), 129–149. https://doi.org/10.1016/j.seps.2006.09.001

Gupta, R., & Gregg, M. (2018). Targeting and modelling urban energy retrofits using a city-scale energy mapping approach. *Journal of Cleaner Production*, *174*, 401–412. https://doi.org/10.1016/j.jclepro.2017.10.262

Hellenic Ministry of Environment and Energy. (2022). *Energy inspections of buildings, heating and air conditioning systems—Statistical analysis for the year 2021 and the period 2011-2021* (p. 44). Hellenic Ministry of Environment and Energy. https://bpes.ypeka.gr/wp-content/uploads/2022_06_30_E%CE%A4%CE%97%CE%A3%CE%99%CE%91_%CE%95%CE%9A%CE%98%CE%95%CE%A3%CE%97_%CE%A3%CE%A4%CE%91%CE%A4%CE%99%CE%A3%CE%A4%CE%99%CE%9A%CE%A9%CE%9D_%CE%91%CE%A0%CE%9F%CE%A4%CE%95%CE%9B%CE%95%CE%A3%CE%9C%CE%91%CE%A4%CE%A9%CE%9D.pdf

Hellenic Statistical Authority. (2023). *Population-housing census results 2021*. https://elstat-outsourcers.statistics.gr/Booklet_%CE%91%CF%80%CE%BF%CF%84%CE%B5%CE%BB%CE%B5%CF%83%CE%BC%CE%B1%CF%84%CE%B1%CE%A0%CE%BB%CE%B7%CE%B8%CF%85%CF%83%CE%BC%CE%BF%CF%852023_II%20GR_FINAL2_WEB.pdf

Koukoufikis, G., & Uihlein, A. (2022). *Energy poverty, transport poverty and living conditions—An analysis of EU data and socioeconomic indicators* (p. 47). Publications Office of the European Union. https://publications.jrc.ec.europa.eu/repository/handle/JRC128084

Kuik, F., Adolfsen, J. F., Meyler, A., & Lis, E. (2022). *Energy price developments in and out of the COVID-19 pandemic – from commodity prices to consumer prices*. https://www.ecb.europa.eu/pub/economic-bulletin/articles/2022/html/ecb.ebart202204_01~7b32d31b29.en.html

López-Vargas, A., Ledezma-Espino, A., & Sanchis-de-Miguel, A. (2022). Methods, data sources and applications of the Artificial Intelligence in the Energy Poverty context: A review. *Energy and Buildings*, *268*, 112233. https://doi.org/10.1016/j.enbuild.2022.112233

Lowes, R., Rosenow, J., Scott, D., Sunderland, L., Thomas, S., Graf, A., Baton, M., Pantano, S., & Graham, P. (2022). *The perfect fit: Shaping the Fit for 55 package to drive a climate-compatible heat pump market*. Regulatory Assistance Project, Agora Energiewende, CLASP, Global Buildings Performance Network. https://www.raponline.org/knowledge-center/the-perfect-fit-shaping-the-fit-for-55-package-to-drive-a-climate-compatible-heat-pump-market/

Magalhães, S. M. C., & Leal, V. M. S. (2014). Characterization of thermal performance and nominal heating gap of the residential building stock using the EPBD-derived databases: The case of Portugal mainland. *Energy and Buildings*, *70*, 167–179. https://doi.org/10.1016/j.enbuild.2013.11.054

Menyhert, B. (2023). *Energy poverty—New insights for measurement and policy* [Scientific analysis or review]. European Commission.

Monzón-Chavarrías, M., López-Mesa, B., Resende, J., & Corvacho, H. (2021). The nZEB concept and its requirements for residential buildings renovation in Southern Europe: The case of multi-family buildings from 1961 to 1980 in Portugal and Spain. *Journal of Building Engineering*, *34*, 101918. https://doi.org/10.1016/j.jobe.2020.101918

Mukelabai, M. D., Wijayantha, K. G. U., & Blanchard, R. E. (2023). Using machine learning to expound energy poverty in the global south: Understanding and predicting access to cooking with clean energy. *Energy and AI*, *14*, 100290. https://doi.org/10.1016/j.egyai.2023.100290

Mulder, P., Dalla Longa, F., & Straver, K. (2023). Energy poverty in the Netherlands at the national and local level: A multi-dimensional spatial analysis. *Energy Research & Social Science*, *96*, 102892. https://doi.org/10.1016/j.erss.2022.102892

Rajić, M. N., Milovanović, M. B., Antić, D. S., Maksimović, R. M., Milosavljević, P. M., & Pavlović, D. L. (2020). Analyzing energy poverty using intelligent approach. *Energy & Environment*, *31*(8), 1448–1472. https://doi.org/10.1177/0958305X20907087

Sareen, S., Thomson, H., Herrero, S. T., Gouveia, J. P., Lippert, I., & Lis, A. (2020). European energy poverty metrics: Scales, prospects and limits. *Global Transitions*, *2*, 26–36. https://doi.org/10.1016/j.glt.2020.01.003

Sousa, J., Bragança, L., Almeida, M., & Silva, P. (2013). Research on the Portuguese Building Stock and Its Impacts on Energy Consumption – An Average U-Value Approach. *Archives of Civil Engineering*, *59*. https://doi.org/10.2478/ace-2013-0029

Spandagos, C., Reaños, M. A. T., & Lynch, M. Á. (2023). Energy poverty prediction and effective targeting for just transitions with machine learning. *Energy Economics*, 107131. https://doi.org/10.1016/j.eneco.2023.107131

Tovar Reaños, M. A. (2021). Fuel for poverty: A model for the relationship between income and fuel poverty. Evidence from Irish microdata. *Energy Policy*, *156*, 112444. https://doi.org/10.1016/j.enpol.2021.112444

van Hove, W., Dalla Longa, F., & van der Zwaan, B. (2022). Identifying predictors for energy poverty in Europe using machine learning. *Energy and Buildings*, *264*, 112064. https://doi.org/10.1016/j.enbuild.2022.112064

Vicente, R., Varum, H., & Mendes da Silva, J. A. R. (2006, September 3). *Vulnerability assessment of traditional buildings in Coimbra, Portugal, supported by a GIS Tool*. First European Conference on Earthquake Engineering and Seismology, Geneva, Switzerland. https://ria.ua.pt/bitstream/10773/8128/1/I_036.pdf

Walker, R., McKenzie, P., Liddell, C., & Morris, C. (2012). Area-based targeting of fuel poverty in Northern Ireland: An evidenced-based approach. *Applied Geography*, *34*, 639–649. https://doi.org/10.1016/j.apgeog.2012.04.002

Zaman, Q. uz, Zhao, Y., Zaman, S., Alenezi, M., & Jehan, N. (2023). Spatial evaluation of multidimensional energy poverty between farming and non-farming communities of agro-climatic zones of Pakistan. *Energy Policy*, *172*, 113294. https://doi.org/10.1016/j.enpol.2022.113294

Annexes

Annex I: Climate, population, housing and living conditions in REVERTER pilots

Table of Contents

List of Figures

List of Tables

1 Pilot 1 - Brezovo (Bulgaria)

1.1 Area characteristics

Geographical position

The municipality of Brezovo is located at the transitional continental climatic sub-region, in the climatic region of Eastern Central Bulgaria having an area of 465.41 km^2. It is located north of the river Maritsa, the terrain is homogeneous with an altitude of 150m, reaching the hilly foothills of Sredna Gora, which contributes to specific processes of orographic origin. The relief of Brezovo municipality is mixed. Low and medium-high mountain areas provide the opportunity for the development of ecological agriculture and animal husbandry. Plain territories are ideal for the development of modern agriculture. The territory allows wide transport accessibility and openness of the town of Brezovo and the settlements attached to the municipality of Brezovo and Maritsa. Water areas are represented in 81 reservoirs with a total area of 6869 decares. The main river that drains and irrigates the territory of Brezovo municipality is the "Rozovska" river. Groundwater is low, making irrigated agriculture difficult.

The most characteristic features of its climate are a pronounced transitional character, in some cases the subtropical influence of the Mediterranean prevails, and in others - the average European continental climate Warm summers and mild winters (average January temperatures are above 0°C), the relatively small annual temperature amplitude, the autumn-winter maximum of precipitation and the lack of annually stable snow cover are common. The average annual air temperature varies between 12.6°C and 13.6°C. Average July temperatures are between 22-24°C, and average January temperatures for the municipality vary from 0 to 1-2°C above zero. Prevailing winds are westerly, with an average annual speed of 1.1 m/s.

1.2 Population characteristics

According to data from Census 2021, the population of Brezovo Municipality has 16 settlements with a total population of 6170 inhabitants. Of these, 1,604 people live in the city of Brezovo, and the remaining 4,696 live in the villages. The predominant ethnic group is Bulgarians. There is a total of 3,241 people of working age, of which 1,839 are men and 1,402 are women. The reduction of the population in the last 10 years is clearly outlined. In numbers it has decreased in 2021 from the previous national census in 2011 by 1128 people or 15.4%.

The conclusion of the analysis of the population census by age is that the population is ageing. As the figure below shows, the highest number of the population is occupied by people over 70 years.

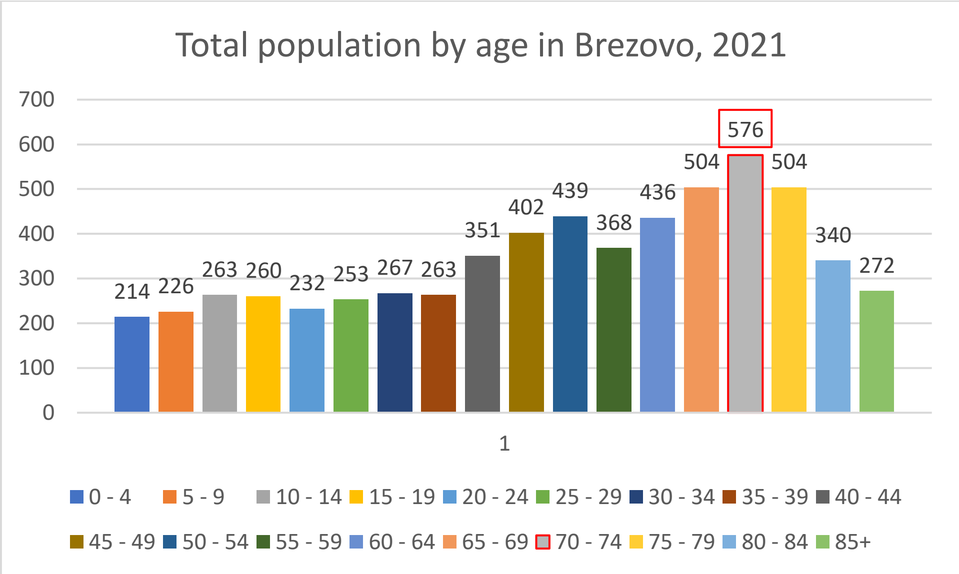


Figure 1 Total population by age in Brezovo (source: NSI)

The trend in population dynamics is characterized by a decrease in the population and, respectively, the number of households.

According to the Municipal action plan for the period 2021-2023, the Municipality of Brezovo has an unfavorable socio-demographic structure. The plan states that unemployment among the able-bodied population in the municipality is 20%. This is an important economic and social problem, which probably affects many spheres of life of the people in the municipality. According to the plan, only three people found work through the Regional Employment Program. This fact may indicate limited opportunities for employment and economic development in the region, which may be a challenge to increase employment. Based on Eurostat indicators, about 30% of the population in the municipality are below the poverty line.

1.3 Housing characteristics

The inhabitants in Brezovo are occupying about 2600-2900 dwellings. The following table represents information about the total number of dwellings in a particular area or region in 2021, broken down into various categories.

Table 1 Total Dwellings by Census 2021 by category

2021					
Total Dwellings by Census 2021					
Total	Dwelling for permanent (usual) residence	Housing for seasonal or vacation residence	A dwelling inhabited by persons who are not subject to the census (foreign diplomats, trade representatives, etc.)	The apartment is collective	The apartment is unoccupied for another reason
6422	2679	2315	-	2	1426

In 2021, there were a total of 6,422 dwellings in the area under consideration. As it could be seen from the figure below, mong the total dwellings, 2,679 (42%) were used for permanent or usual residence. There were 2,315 (36%) dwellings designated for seasonal or vacation residence. According to the Census data, there were 2 apartments classified as "collective”, which refer to housing units shared by multiple unrelated individuals or families. The Census analysis indicates that there were 1,426 (2%) apartments unoccupied for reasons other than being a seasonal or vacation residence. This category may include vacant properties for various reasons, such as being in the process of sale, renovation, or other non-residential purposes.

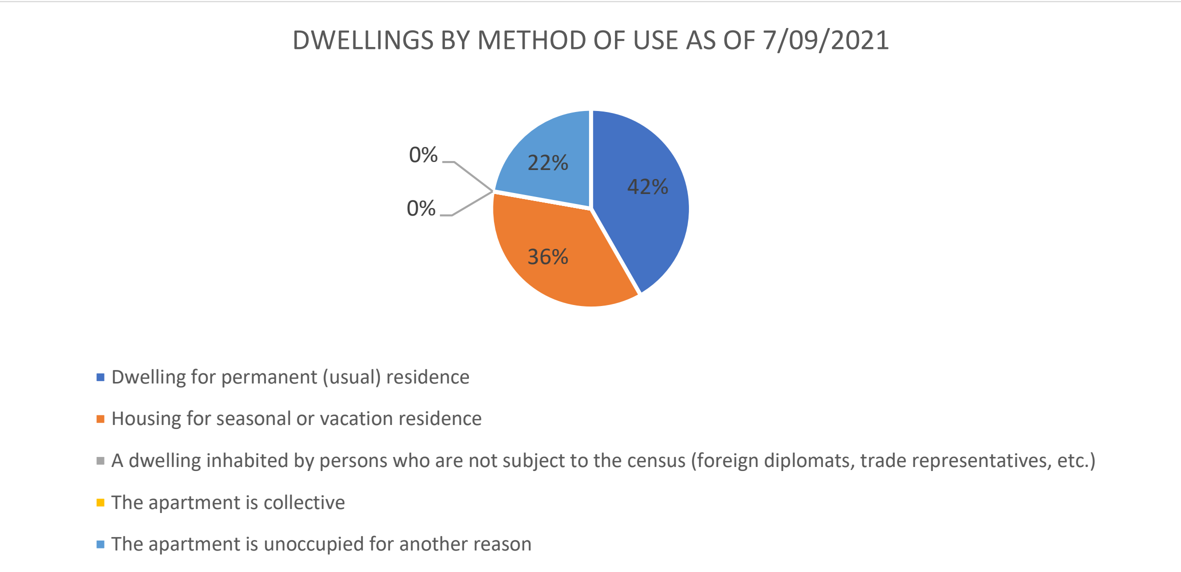


Figure 2 Dwellings by method of use as of 7/09/2021 (based on NSI data)

The majority of dwellings are private single houses with low levels of efficiency (>95%). In 2019, the final energy consumption of the Municipality was estimated at 44.85 GWh. The housing sector is responsible for 26.64 GWh of the total energy consumption, taking the largest share or 59.4%. The use of raw wood for domestic heating is dominant (47%), followed by electricity (39%) and coal (12%). This is a prerequisite for high PM pollution during the heating season. The housing sector is responsible for 10,247 tons of greenhouse emissions. The technical potential of the possible recovery of the waste streams from the agricultural sector and animal waste is calculated for the production of 5,900 MWth. The Municipality is also rich in forestry. Residual biomass from logging is equal to 7,460 tons of wood, whose energy equivalent is equal to 38,250 MWh of heat.

The results from the National Census, shows that 74% of the dwellings in Brezovo have no renewed windows (Figure 3), and 91% of the dwellings are without insulation (Figure 4).

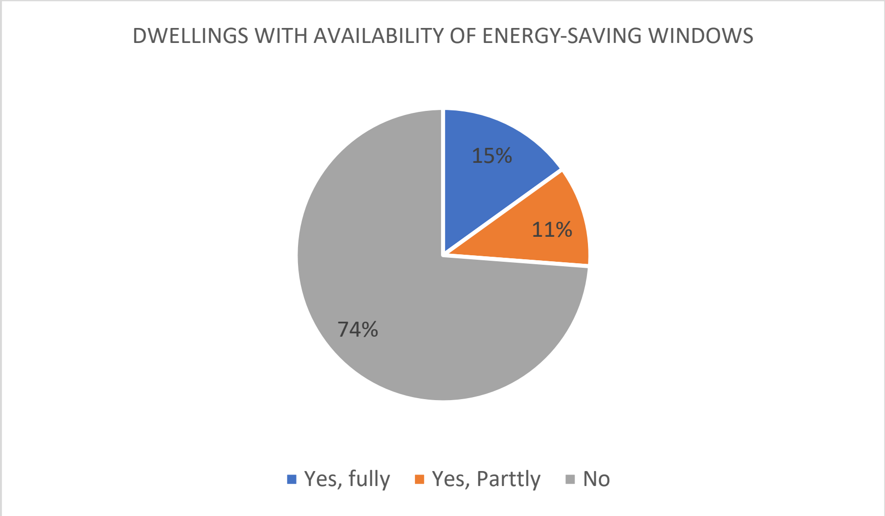


Figure 3 Dwellings with availability of energy-saving windows as of 09/07/2021 (Source: https://infostat.nsi.bg/)

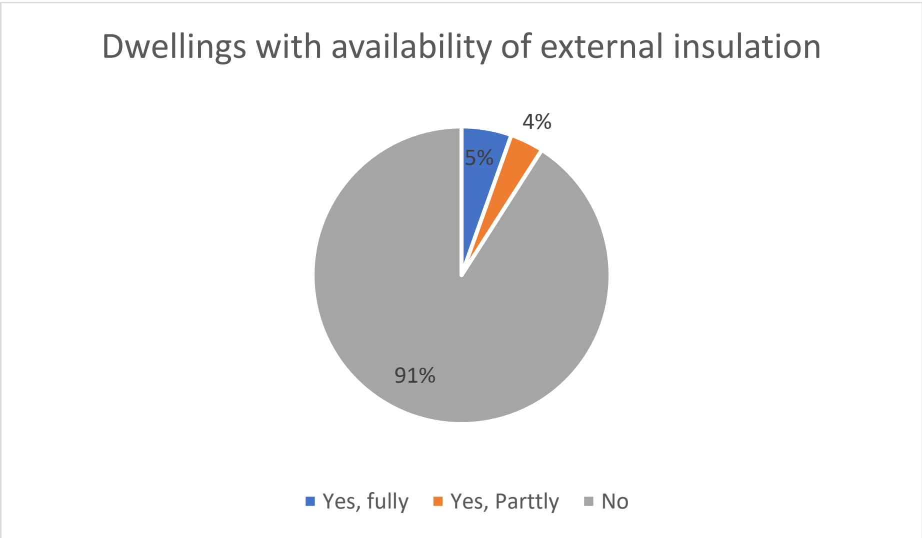


Figure 4 Dwellings with availability of external insulation as of 7/09/2021 by the National Census 2021

According to the Municipal Energy Efficiency Program, the residential sector of the municipality of Brezovo occupies the largest percentage of the municipality's final energy consumption – 59.4%, consuming a total of 26.6 GWh of energy. Looking at the percentage of energy sources used, the dominant use is the use of raw wood for domestic heating (47%), followed by the consumption of electricity (39%) and coal (12%). Heating is based mostly on the use of wood and coal and a minor share of electricity. The high levels of use of wood and coal are a prerequisite for influencing the air quality.

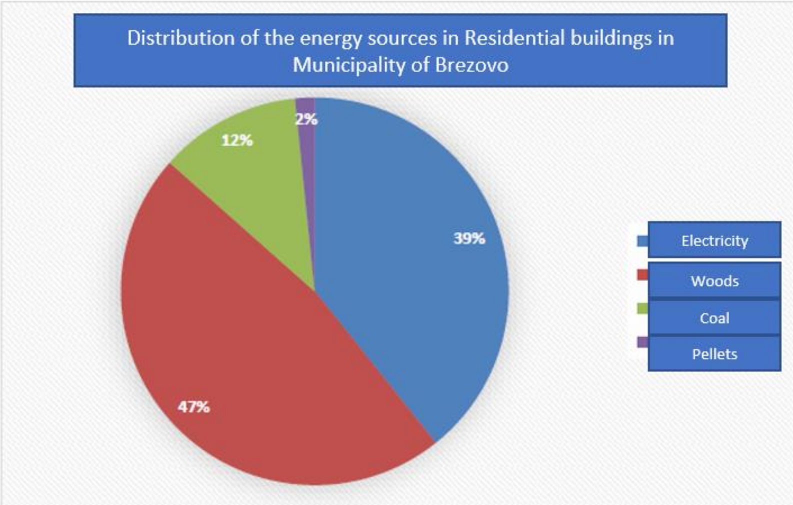


Figure 5 Distribution of energy sources in residential buildings in Municipality of Brezovo (Source: Municipal Energy Efficiency Program)

1.4 Energy poverty and vulnerability

The analysis of the current situation of energy poverty and vulnerability of the population in the area of the Brezovo pilot was based on data from Eurostat's EU SILC and HBS surveys. More specifically, the National Statistical Institute of the Republic of Bulgaria provided EU SILC survey microdata (at household level) for the years 2017-2021 and HBS data for the years 2017-2019 and 2021. Nevertheless, the HBS data didn't include derived variables at household level referring to household size and type, equivalent size, number of persons per age class, number of persons who are working or are unemployed, etc. From the dataset, the observations selected were those that referred to region BG42 (variable DB040) and degree of urbanisation 3 (variable DB100 - rural area/thinly populated area). This subset of the data includes other areas than Brezovo, but with similar characteristics.

As shown in Figure 6, the share of population living in a dwelling with leaks, damp or rot in the area of the Bulgarian pilot is higher than the national share (almost by 1-2%). The same is true for the share of population not able to keep home adequately warm (Figure 7). However, the difference decreases over the years (i.e., from 8.9% in 2017 to 1.5% in 2021). In contrast, the share of population having arrears on utility bills is lower in the pilot area compared to the national indicator (Figure 8). Again, the difference decreases over the years (i.e., from 10.3% in 2019 to 3.1% in 2021). In general, it appears that the consensual EP indicators in the pilot area are approaching the corresponding national indicators over time and, as is the case nationally, are improving.

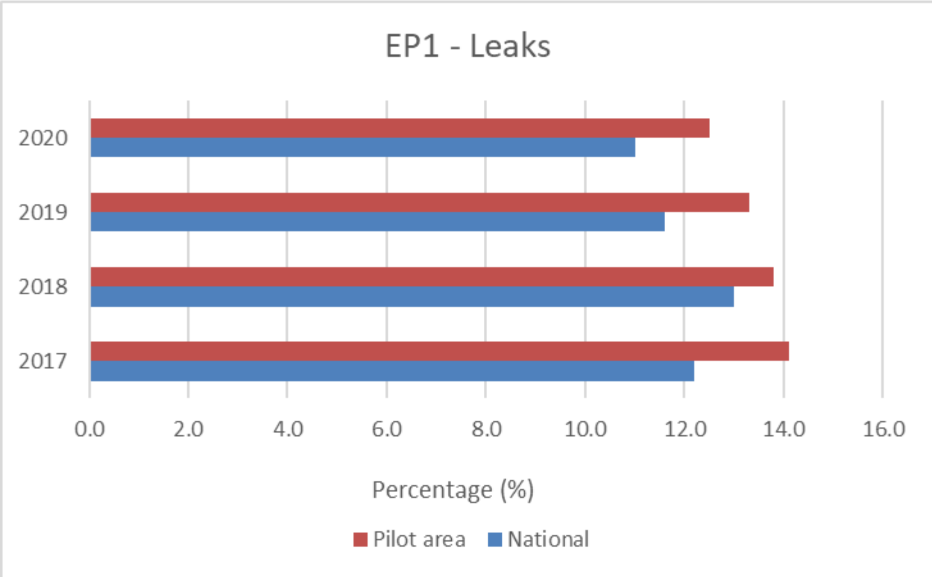


Figure 6. Share of total population living in a dwelling with leaks

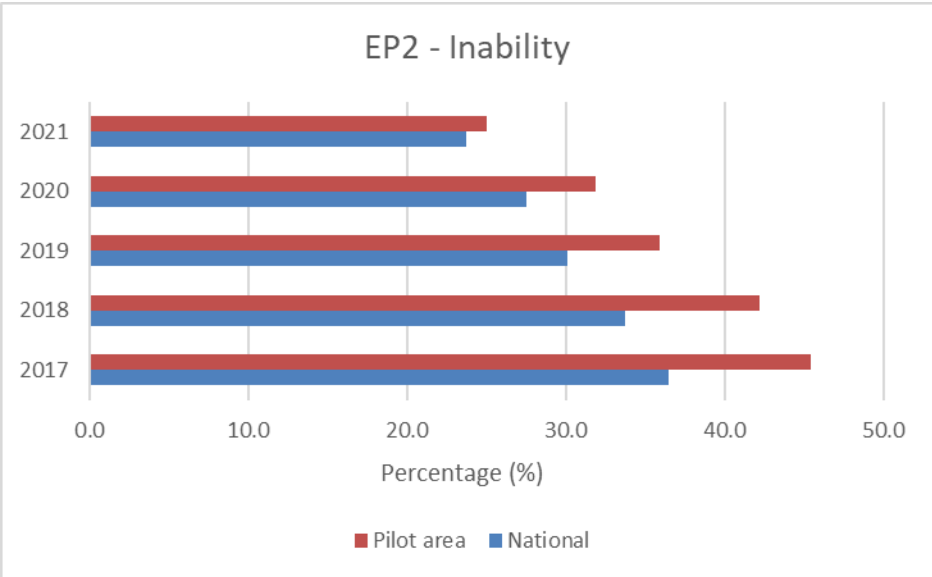


Figure 7. Share of population not able to keep home adequately warm

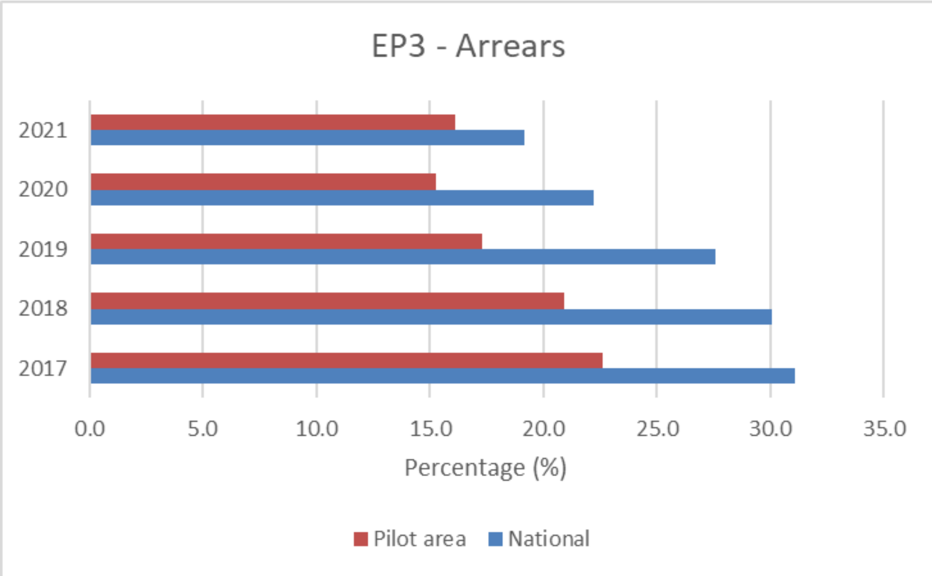


Figure 8. Share of population having arrears on utility bills

The rest of EP indicators (i.e., EP4 to EP12) were studied only at the pilot area level, as they are not official indicators. Looking at Figure 9 and Figure 10, it can be seen that the share of population having arrears on utility bills only once is more or less stable (around 8%) but the corresponding share of those who have arrears on their bills twice or more has been significantly reduced (by more than 40% in the last five years).

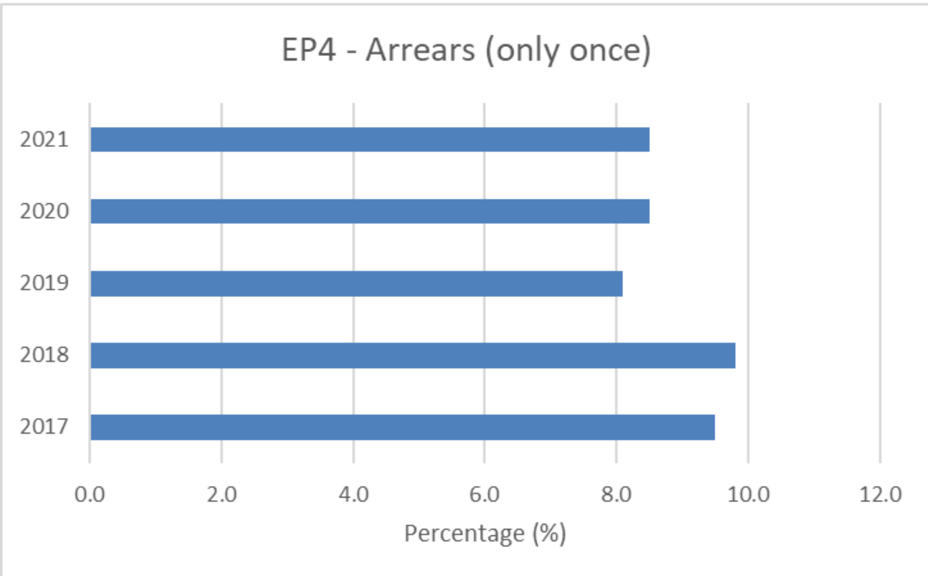


Figure 9. Share of population having arrears on utility bills only once in the past 12 months

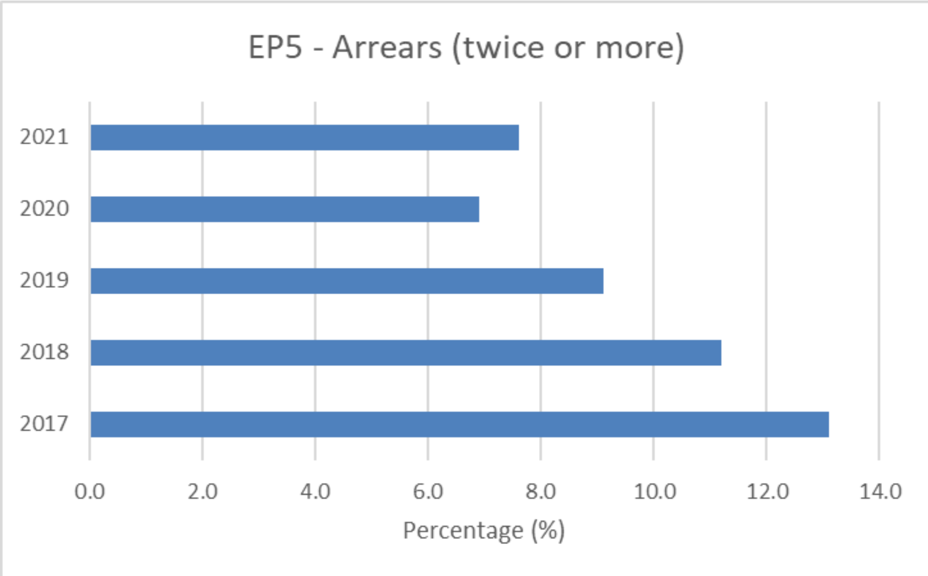


Figure 10. Share of population having arrears on utility bills twice or more in the past 12 months

The reduction in the intensity of the problem is also reflected in the results of the Weighted Composite Indices (WCI). As shown in Figure 11, the percentage of the population not experiencing EP issues increased from 43% in 2017 to 55.3% in 2020. More importantly, the percentage of those experiencing severe EP issues (i.e., the WCI1 is equal to 1) has been reduced by around 50%, from about 4% to 2%. Similar conclusions are drawn from Figure 12 (WCI2) and Figure 13 (WCI3).

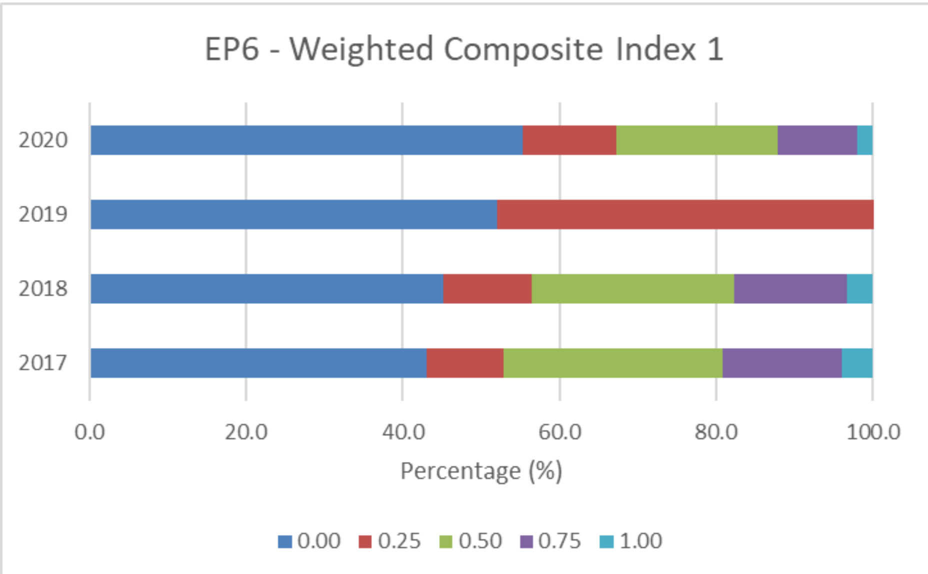


Figure 11. Share of population at EP according to WCI1

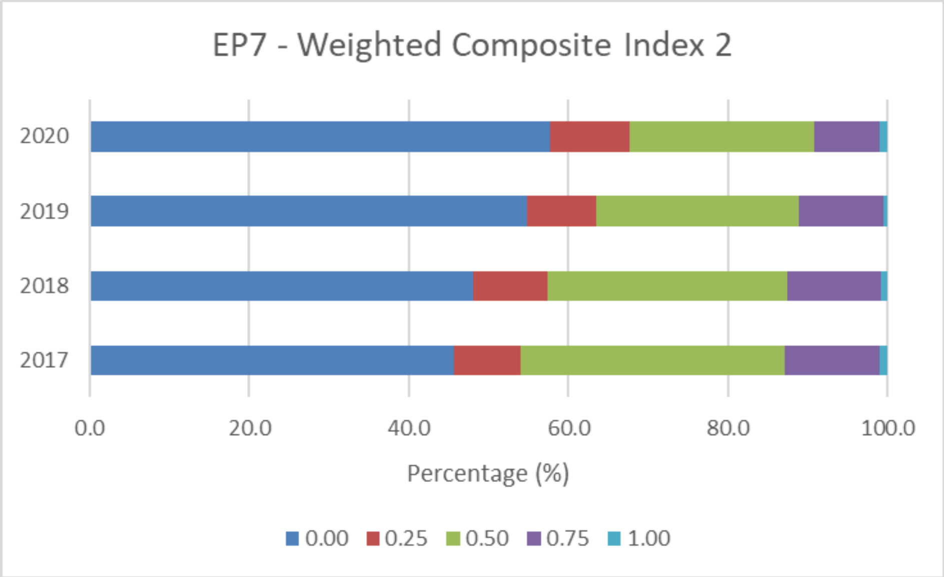


Figure 12. Share of population at EP according to WCI2

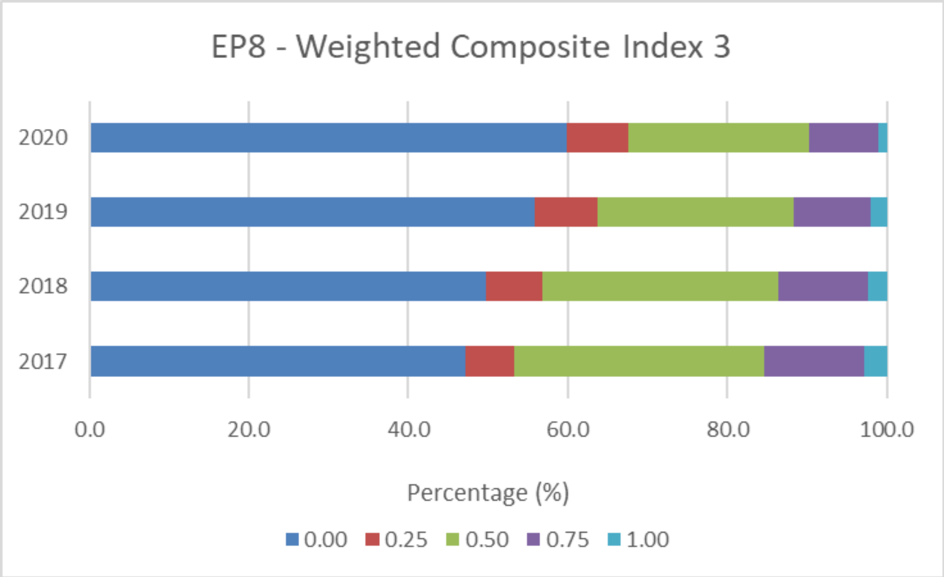


Figure 13. Share of population at EP according to WCI3

The Simple Composite Indices (SCI) reveal a similar pattern of EP evolution. In all SCIs (Figure 14, Figure 15 and Figure 16), the share of the population not experiencing EP issues is increasing and the proportion experiencing the most important EP problems (classes 2 and 3) is decreasing. For instance, according to SCI3 (Figure 16) the EP rate for class 2 has been reduced from 13.9% to 9.1% (a percentage reduction of 34.4%) and for class 3 from 2.9% to only 1% (a percentage reduction of 63.9%).

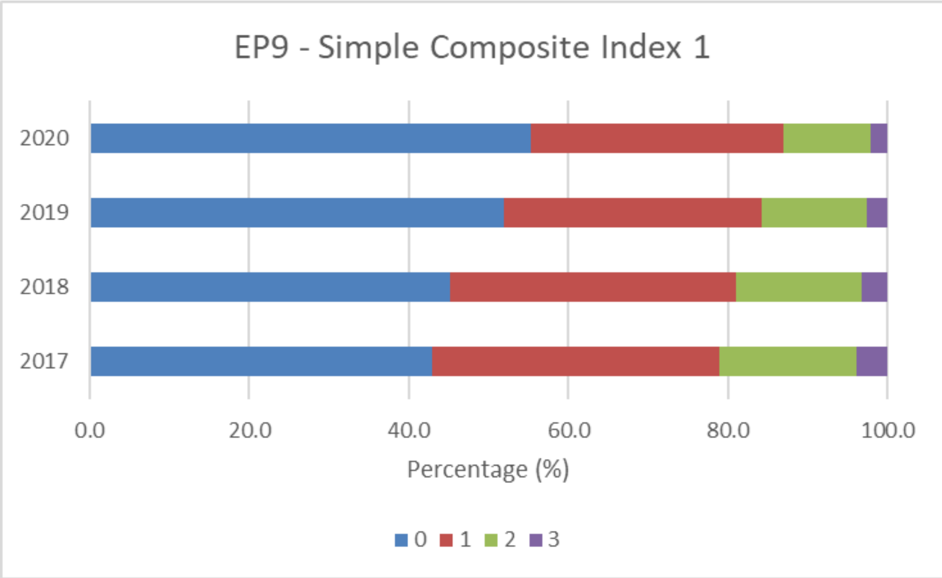


Figure 14. Share of population at EP according to SCI1

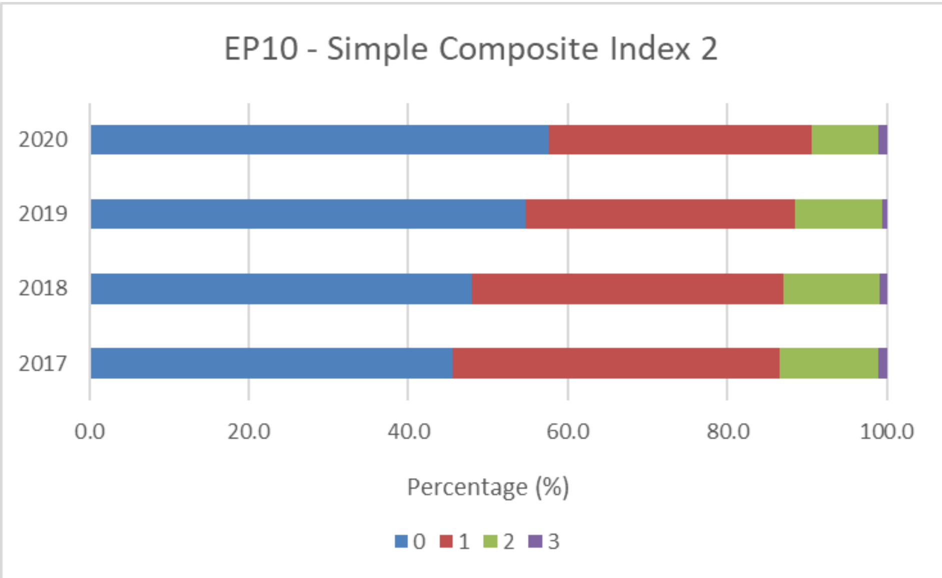


Figure 15. Share of population at EP according to SCI2

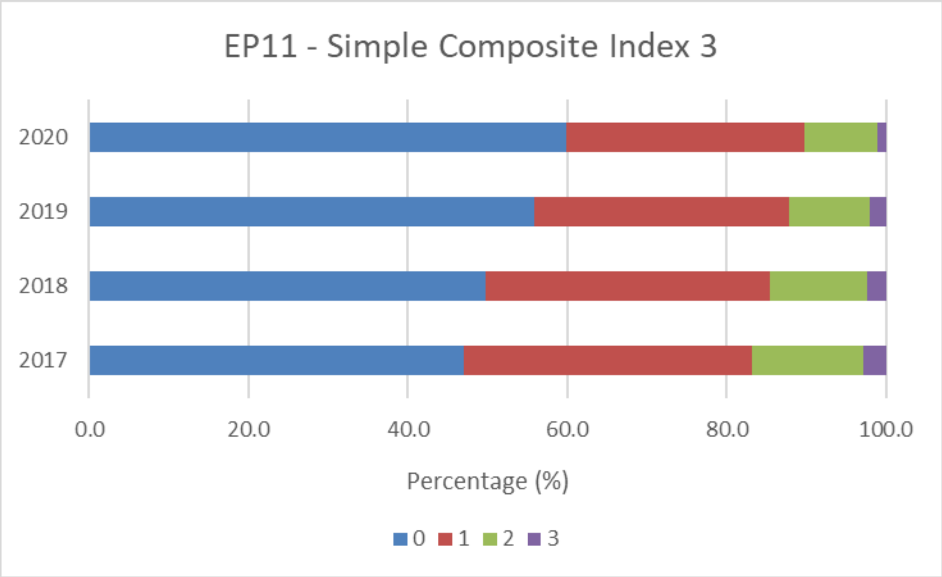


Figure 16. Share of population at EP according to SCI3

Finally, the proportion of the population in the pilot area that experiences any type of EP, i.e., arrears on utility bills, leaks or inability to keep their house warm, presents also a decreasing trend (Figure 17). It may be redundant, but it should be noted that the percentage of EP households is significantly high based on this indicator, as practically all individual energy poverty indicators are added together.

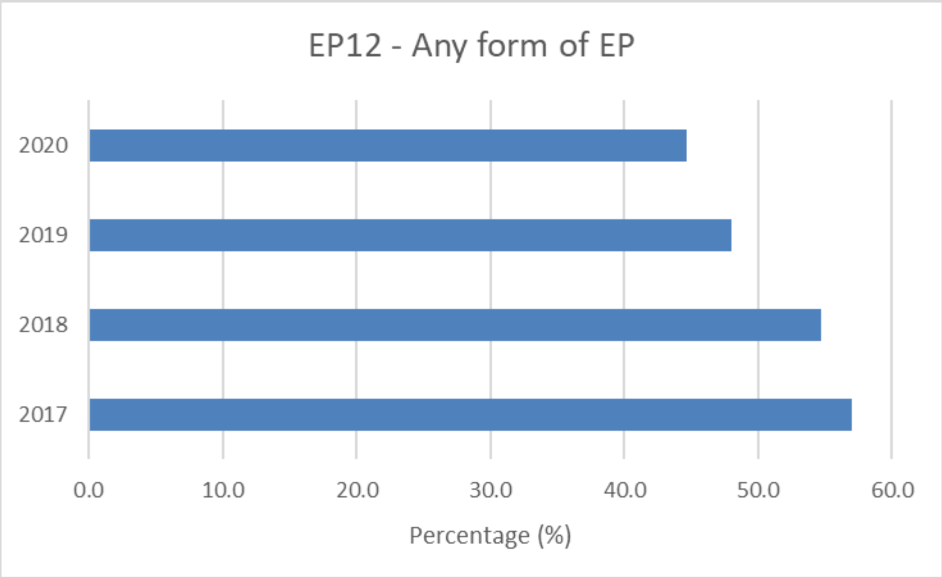


Figure 17. Share of population at EP according to EP12

In order to explore whether certain housing characteristics and households' living conditions are related to EP vulnerability, the difference in EP rates of the investigated indicators relative to their average rate in the pilot area was examined.

As illustrated in Figure 18, households living in large buildings are less prone to arrears and more capable to keep their apartments adequately warm compared to those living in small buildings, detached or semi-detached houses. Also, those living in small buildings face higher problems with leaks. These findings can be related to the fact that a large part of detached houses was built before the introduction of national energy efficiency legislation, while a large part of multi-family residential buildings was built after 1960, when the first norms and requirements for energy efficiency were introduced.

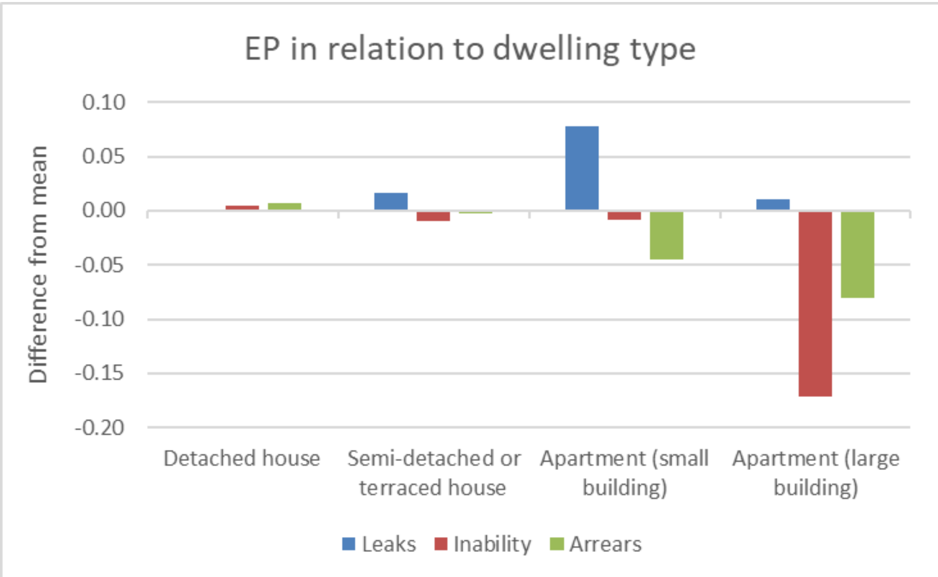


Figure 18. Leaks, inability to keep house warm and arrears on utility bills in relation to dwelling type

The size of the house is also associated with the three basic EP indicators, according to Figure 19. Those living in one- or two-room houses have higher EP rates compared to the average, while those living in houses with four or more rooms have lower EP rates. Again, the most likely explanation for this result is the difference in income. For example, the average income of the households that live in one- or two-room houses ranges between 3,200-4,200 EUR, while the average income of the households living in houses with more than four rooms is more than 9,500 EUR, on average.

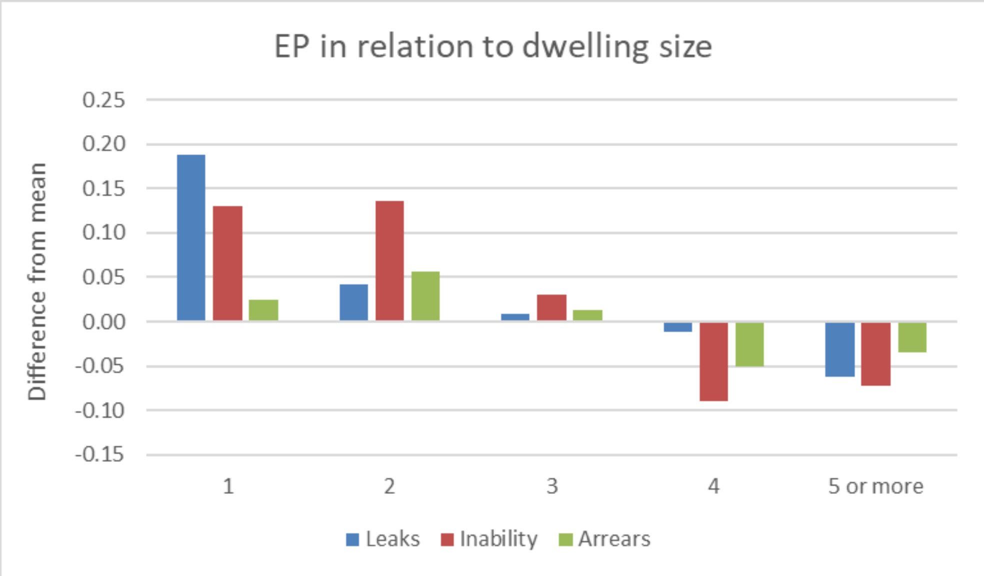


Figure 19. Leaks, inability to keep house warm and arrears on utility bills in relation to dwelling size

As far as tenure status is concerned, the most vulnerable groups to EP are tenants who pay rent (either at market or at reduced rate). These results should however be viewed with caution because the number of observations in these categories is very small (less than 15).

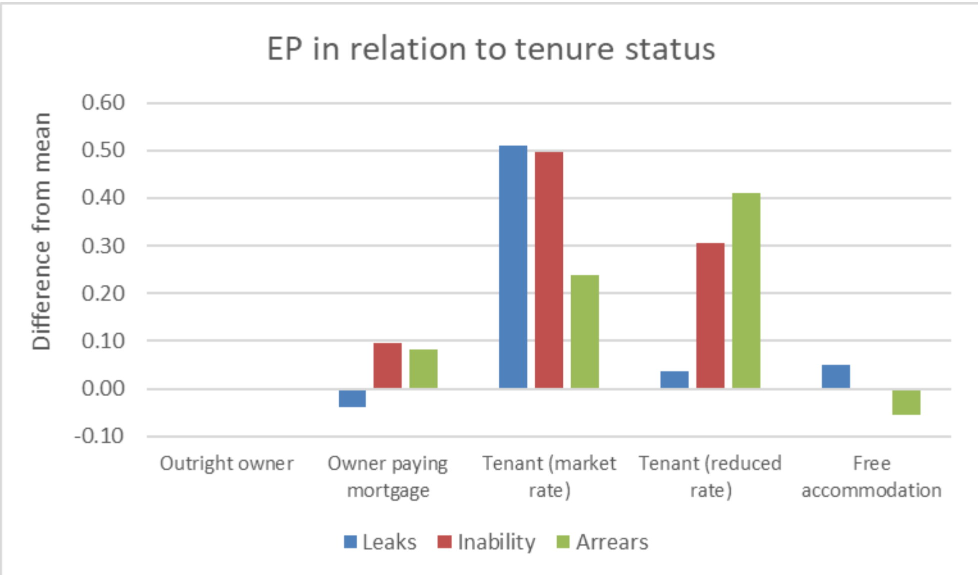


Figure 20. Leaks, inability to keep house warm and arrears on utility bills in relation to tenure status

The role of income in energy poverty becomes evident in Figure 21. Households experiencing great difficulty in making ends meet have differences in EP rates of up to 30% compared to the average rates. On the contrary, those who can pay easily for their usual necessary expenses have quite lower EP rates (e.g., differences from the average of more than 30% in the ability to keep their houses warm).

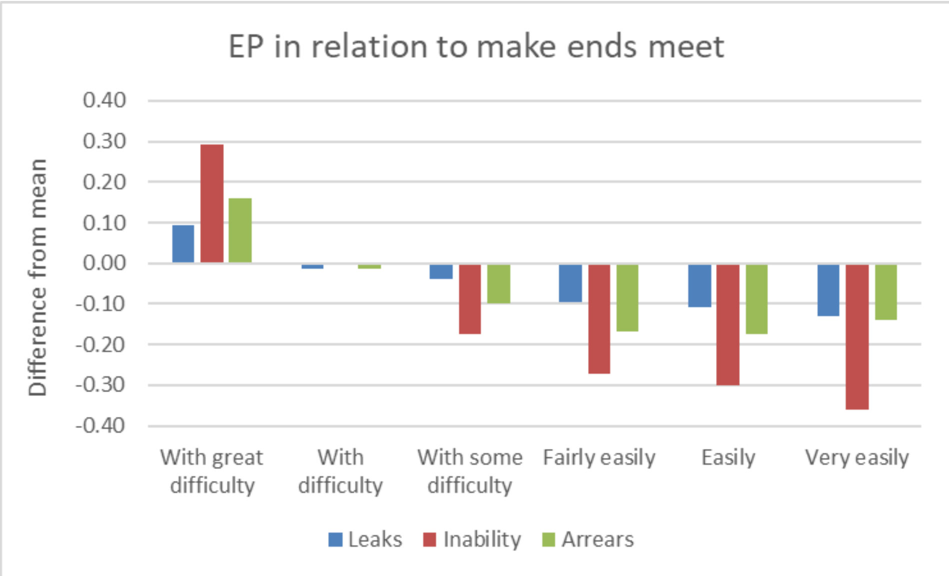


Figure 21. Leaks, inability to keep house warm and arrears on utility bills in relation to the level of difficulty in making ends meet

The above-mentioned patterns are observed, and are even more pronounced, in the complementary EP indicators. For instance, in Figure 22, households living in small buildings are more energy vulnerable, while the opposite is true for those living in large buildings. Tenants (Figure 24) and those living in one- or two-room homes (Figure 23) are also more energy vulnerable. Finally, those who find it difficult to make ends meet present scores, in all EP indicators, higher than the average, while those who live comfortably score lower than the average (Figure 25).

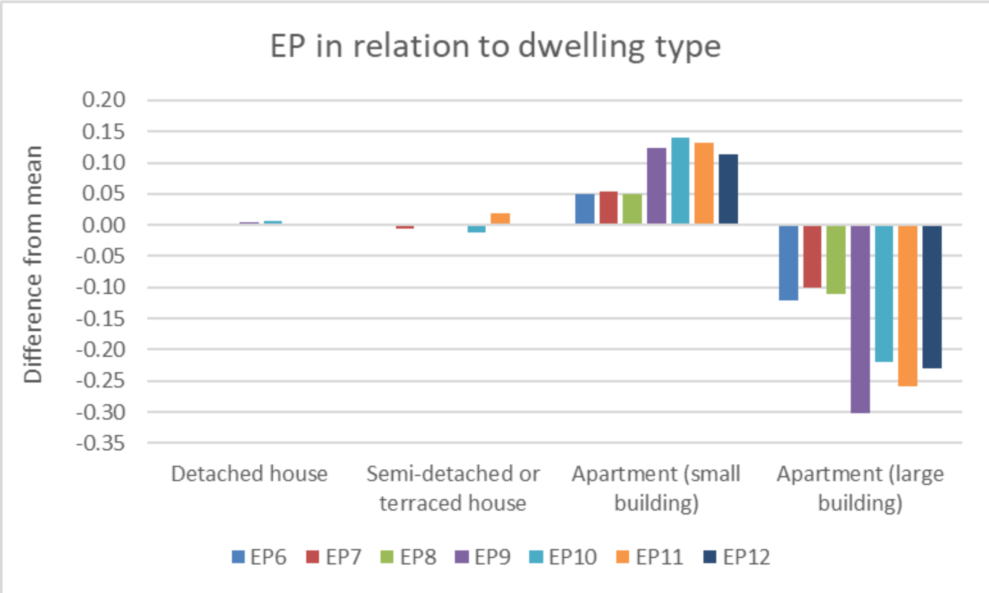


Figure 22. Complementary EP indicators in relation to dwelling type

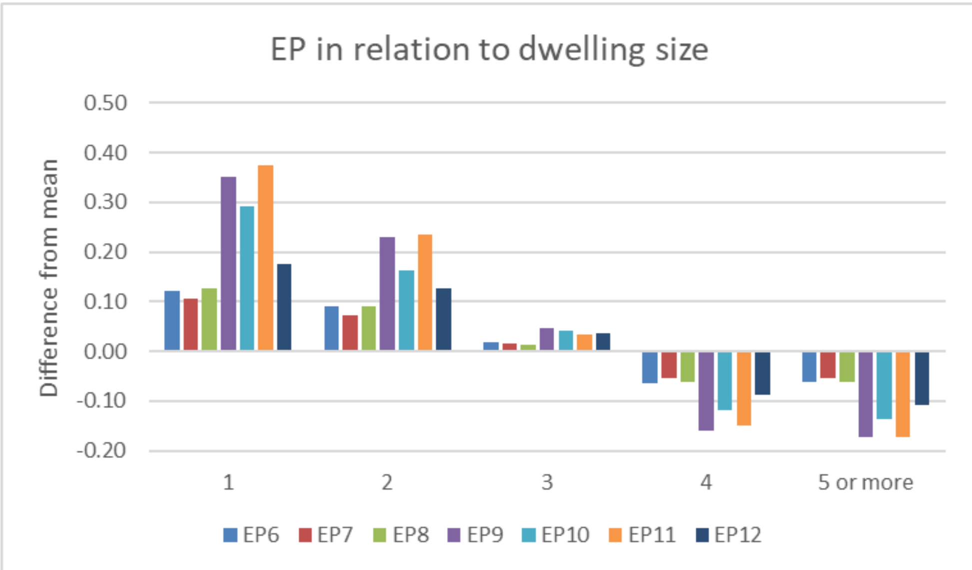


Figure 23. Complementary EP indicators in relation to dwelling size

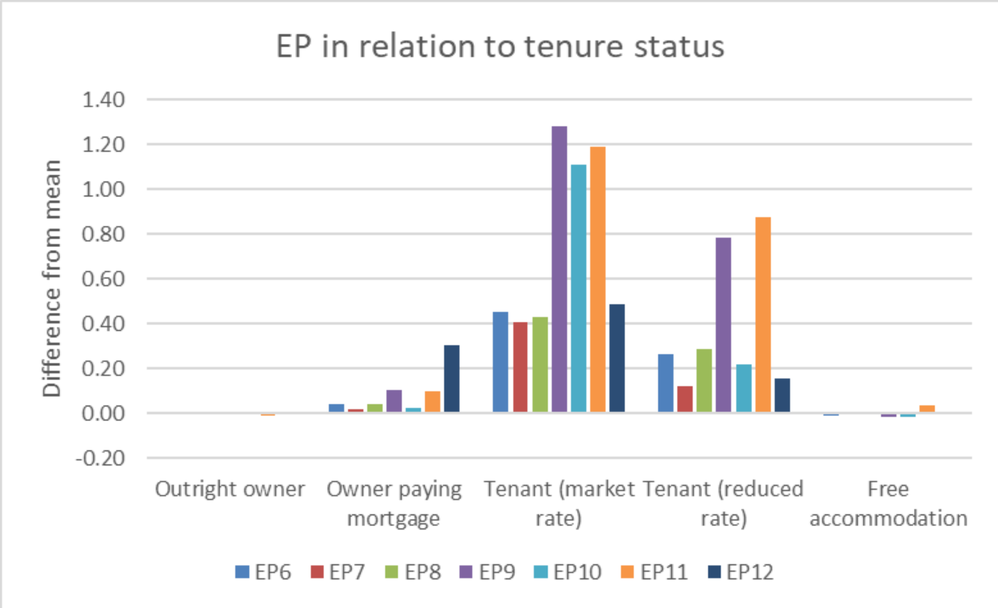


Figure 24. Complementary EP indicators in relation to tenure status

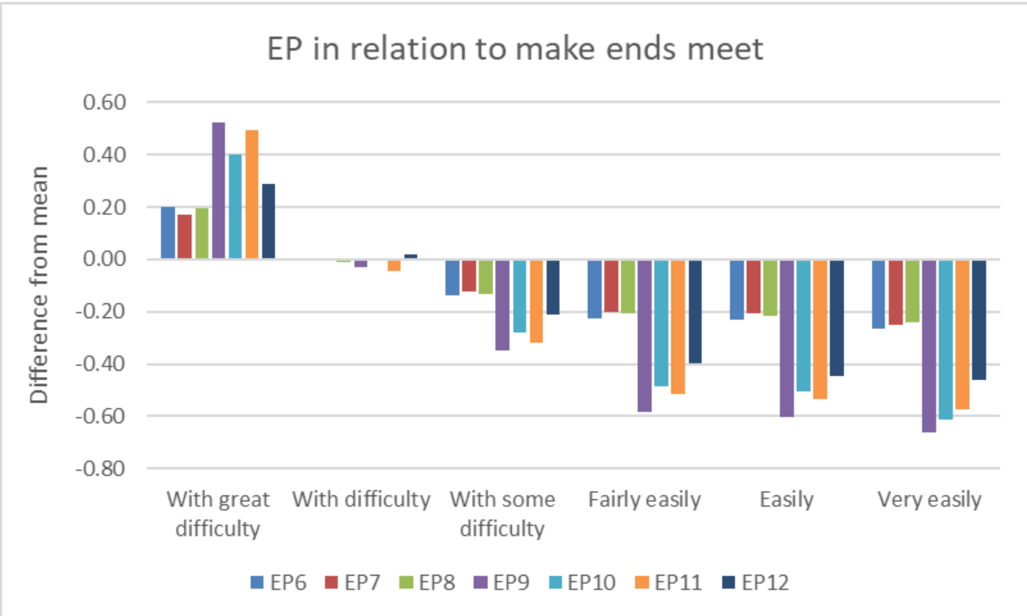


Figure 25. Complementary EP indicators in relation to the level of difficulty in making ends meet

As mentioned, Bulgarian HBS dataset didn't include derived variables at household level referring to household size and type, equivalent size, number of persons per age class, number of persons who are working or are unemployed, etc. Therefore, four EP expenditure indicators were formed and calculated, based on previously used (e.g., the "10% rule") or modified (e.g., variations of 2M and M2 indicators) and other indicators suggested by scholars (e.g., the "25% threshold", a variation of the "FixThreshold" indicator proposed by (Menyhert, 2023).

Based on Figure 26 to Figure 29, the following remarks can be made:

- After an increase in 2018, all EP expenditure indicators decline steadily. The same pattern is observed in the consensual-based EU SILC indicators.
- According to the Low Expense, High Expense and “25% threshold” indicators, the share of population facing EP problems is around 15%, on average. The “10% rule” seems to overestimate the EP problem (more than half of the population is characterised as EP).
- The EP levels in the area of interest, i.e., the Brezovo pilot, are higher than the national averages for all four indicators by around 11% (for the “10% rule” indicator) to more than 75% (for the Low Expense indicator).
- The gap between the pilot area and the national average is gradually narrowing for three indicators, i.e., “10% rule”, High Expense and “25% threshold”. Nevertheless, the gap increases for the Low Expense indicator, i.e., from 55.6% in 2019 to 76.2% in 2021.

Figure 26. Share of population whose absolute level of energy expenditures is less than half the national median

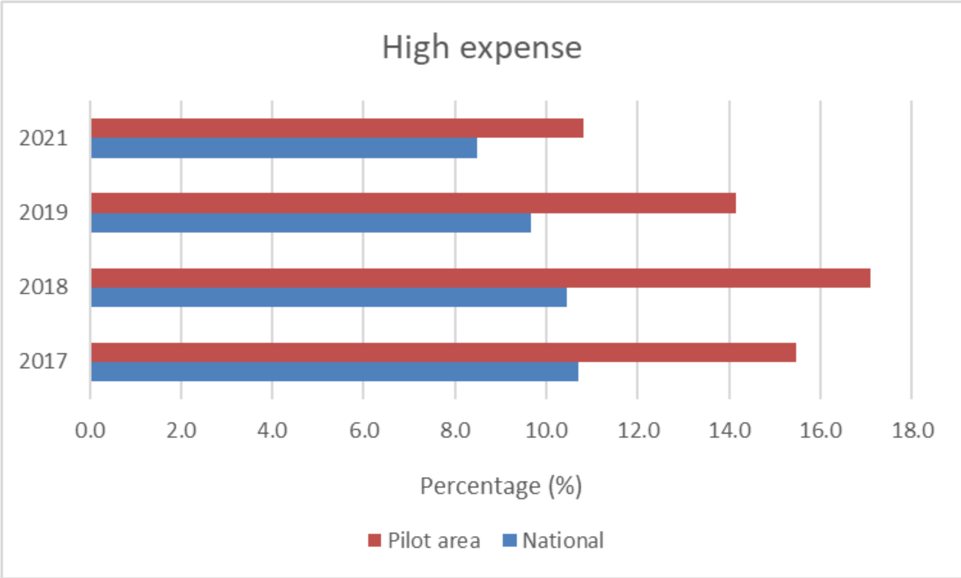


Figure 27. Share of population whose energy expenditure-to-income ratio is more than twice the national median

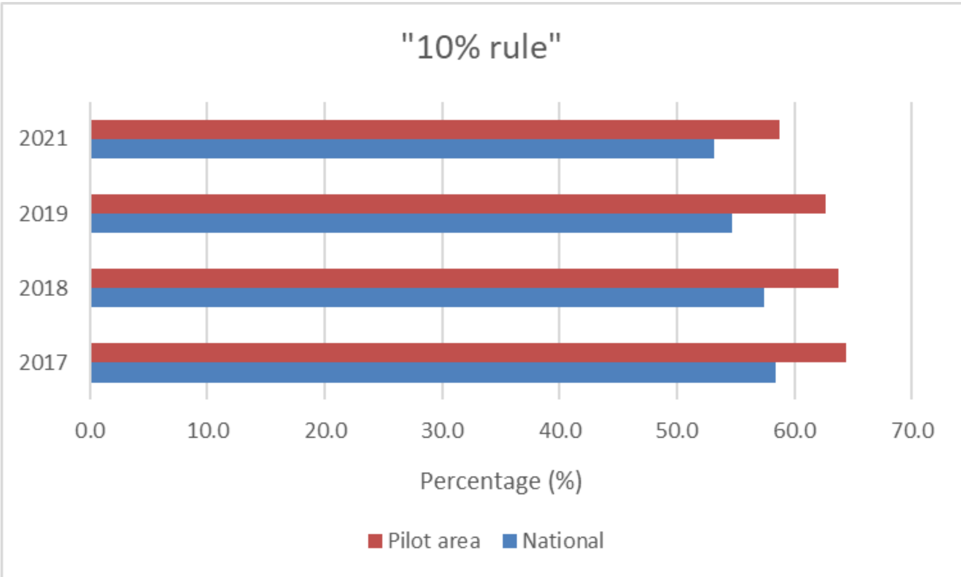


Figure 28. Share of population whose absolute level of energy expenditure is more than 10% of their income

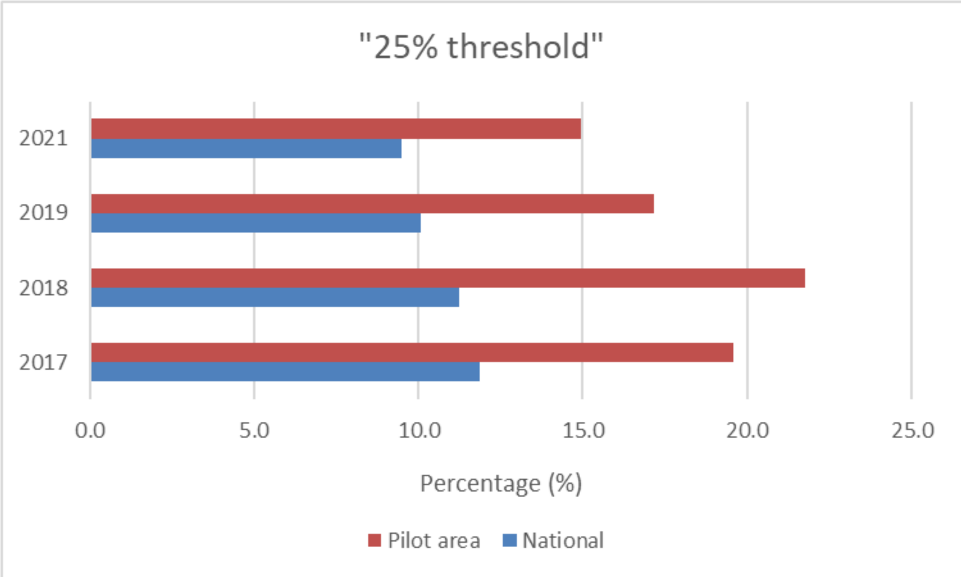


Figure 29. Share of population whose energy expenditure exceeds 25% of total expenditures

To explore the role of income, ten different income classes were created using the median national income per year, as follows:

- Income class 1 - below 20% of the national median income
- Income class 2 - between 20% and 40% of the national median income
- Income class 3 - between 40% and 60% of the national median income
- Income class 4 - between 60% and 80% of the national median income
- Income class 5 - between 80% and 100% of the national median income
- Income class 6 - between 100% and 120% of the national median income
- Income class 7 - between 120% and 140% of the national median income
- Income class 8 - between 140% and 160% of the national median income
- Income class 9 - between 160% and 180% of the national median income
- Income class 10 - over 180% of the national median income

Moreover, because in some income classes the number of observations was relatively low, the ten income classes were grouped into three income categories, i.e., low-income households (Income classes 1 to 3, i.e., those who have income below 60% of the national median income); middle-income households (Income classes 4 to 7, i.e., those who have income between 60% and 140% of the national median income); and high-income households (i.e., those who have income over 140% of the national median income).

As shown in Figure 30 and, especially, in Figure 31, there is an unquestionable correlation between EP and income for all indicators. For example, the share of the population experiencing EP issues based on Low Expense indicator is more than three times higher in the low-income class compared to the middle-income class, and 5.5 times higher compared to the high-income class.

Similar conclusions can be drawn from the other HBS EP indicators. Taking into account that, as a rule, low-income households live in low energy-efficient houses and, in addition, these households are unable to retrofit their houses for financial reasons, it exacerbates the problem and traps them in a vicious cycle.

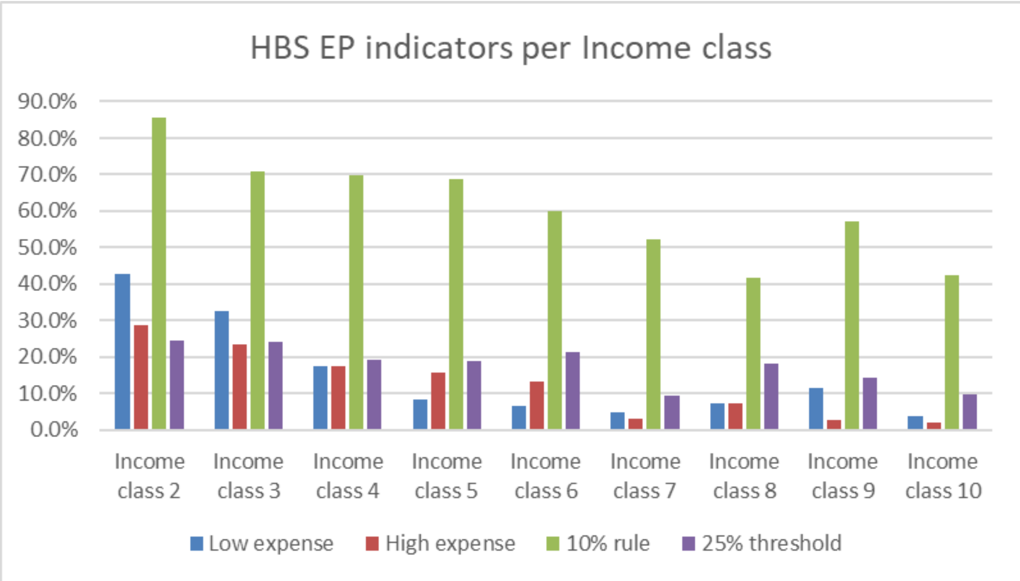


Figure 30. HPS expenditure-based EP indicators in relation to the level of income

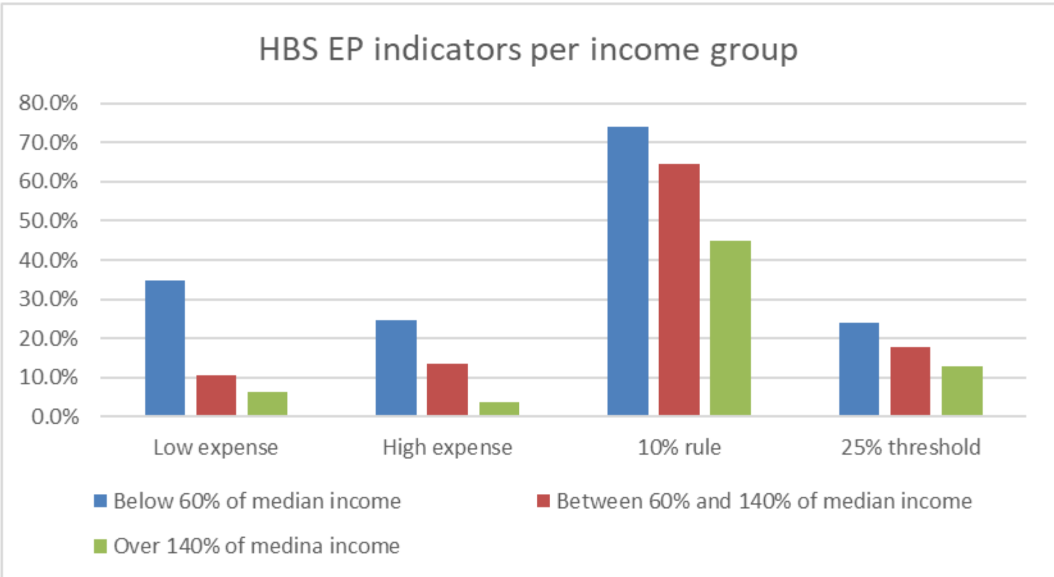


Figure 31. HPS expenditure-based EP indicators per income group

2 Pilot 2 - Athens Urban area (Greece)

2.1 Area characteristics

The Athens Urban Area, also known as “Athens - Piraeus Urban Complex”, forms the core and centre of Greater Athens and stretches across the Attica Basin over an area of 412 km², in Attica, the highest-populated region in Greece (Figure 32).

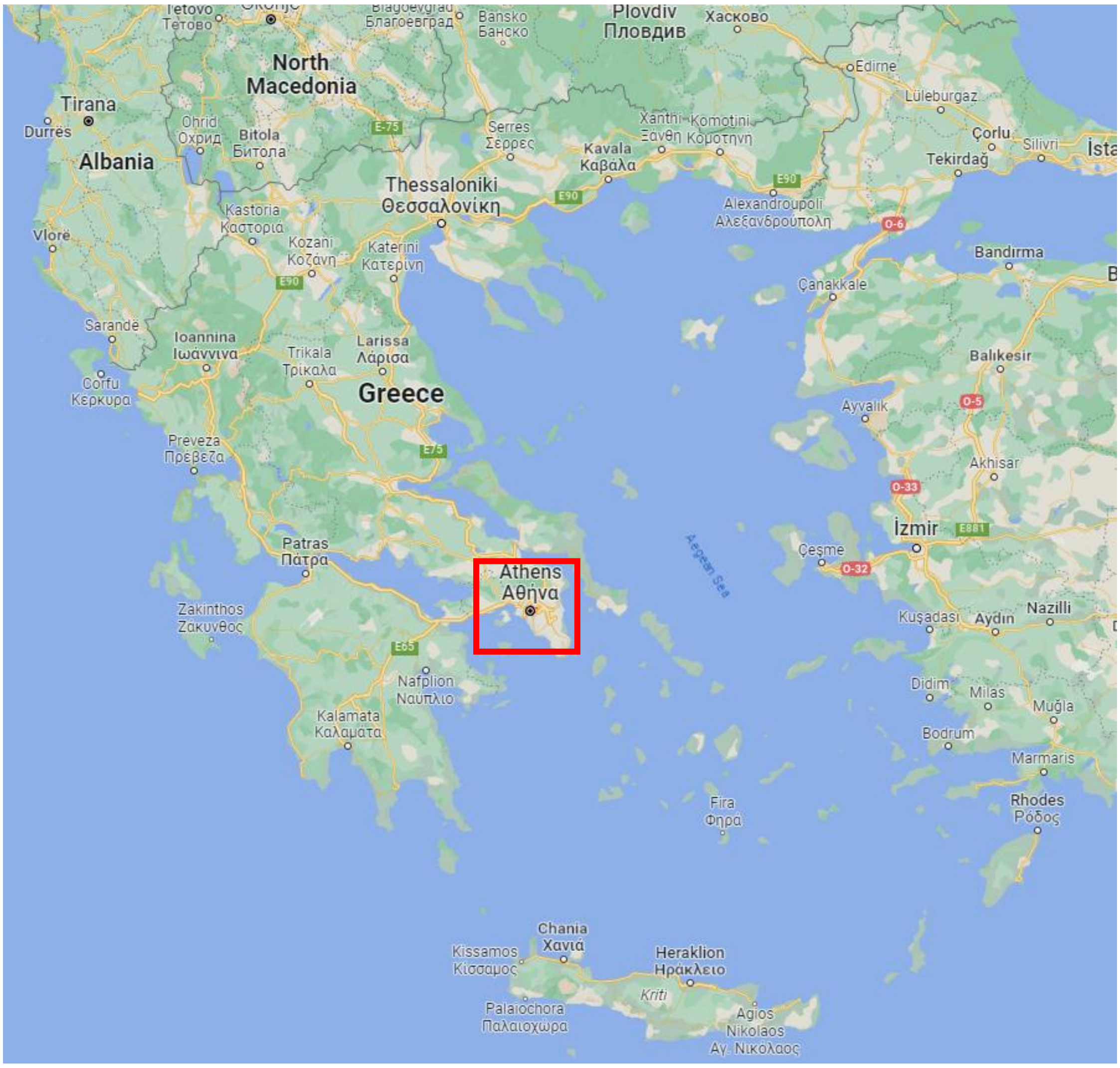


Figure 32. Location of the Greek pilot (Source: Google Maps)

In the new “Athens - Attica Regulatory Plan” (L. 4277/2014, Government Gazette Issue 156A, 01/08/2014), the Athens Urban Area is referred to the “Athens - Piraeus Spatial Unit”, and consists of 40 municipalities, 35 of which are located within 4 regional units of the former Athens Prefecture (North Athens, West Athens, Central Athens, South Athens), and 5 municipalities are located within the regional unit of the former Piraeus Prefecture, as follows (Figure 33):

- Central Athens Municipalities: Athens, Nea Philadelphia - Nea Chalkidonia, Galatsi, Zografou, Kaisariani, Byronas, Ilioupoli and Daphne - Ymittos.
- North Athens Municipalities: Penteli, Kifissia, Metamorphosis, Lykovrisi - Pefki, Maroussi, Filothei - Psychiko, Papagos - Cholargos, Nea Ionia, Heraklion, Vrilissia, Agia Paraskevi and Halandri.
- South Athens Municipalities: Glyfada, Elliniko - Argyroupoli, Alimos, Nea Smyrni, Moschato - Tavros, Kallithea, Paleo Faliro and Agios Dimitrios.
- West Athens Municipalities: Egaleo, Peristeri, Petroupoli, Haidari, Agia Varvara, Ilion and Agioi Anargyroi - Kamatero.
- Piraeus region Municipalities: Piraeus, Korydallos, Nikaia - Agios Ioannis Rentis, Keratsini - Drapetsona and Perama.

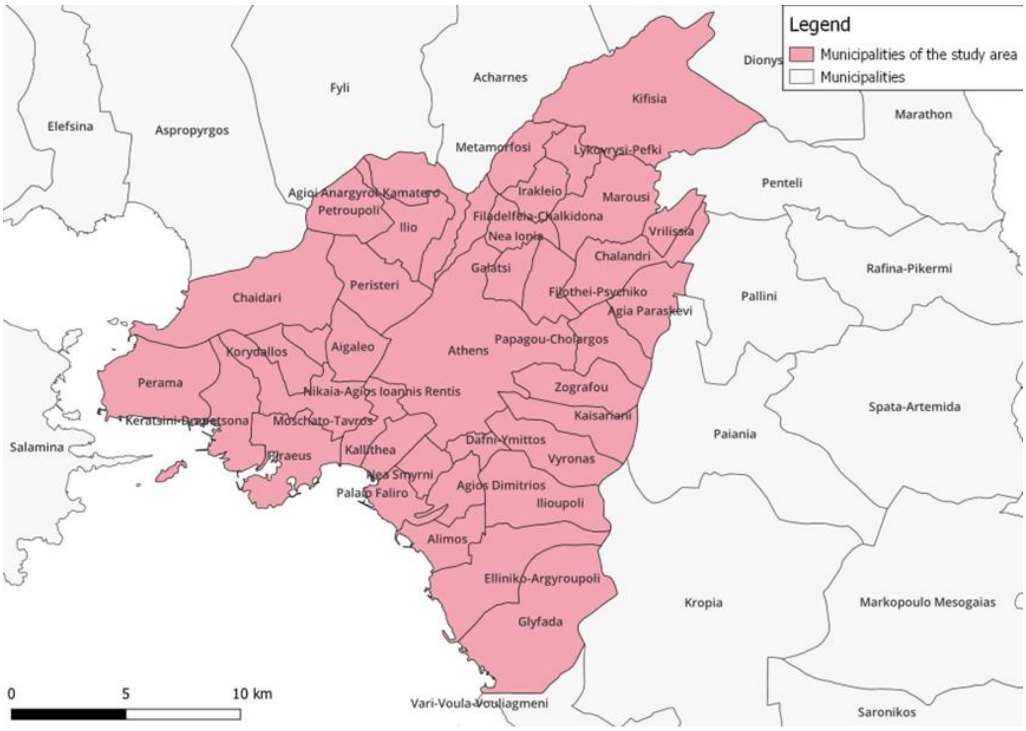


Figure 33. The Athens Urban Area

The climate of the Area is mild. As shown in Table 2, the average annual temperature over the last 30 years (1991-2020) is 18.5°C, the total annual precipitation is roughly 433 mm, and the average humidity is 61% (Founda & Pierros, 2021).

Table 2. Athens climate data (1991-2020)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Average temp. °C	9.7	10.2	12.5	16.1	21.1	26.0	28.7	28.5	24.1	19.4	14.9	11.1	18.5
Average max °C	13.3	14.2	17	21.1	26.5	31.6	34.3	34.3	29.6	24.4	18.9	14.4	23,3
Average min °C	7.1	7.3	9.2	12.3	17	21.6	24.2	24.4	20.4	16.2	12.2	8.7	15.0
Rainfall mm	55.6	44.4	45.6	27.6	20.7	11.6	10.7	5.4	25.8	38.6	70.8	76.3	433.1
Humidity %	72	70	66	60	56	50	42	47	57	66	72	73	60.9

Source: (Founda & Pierros, 2021)

The following tables (Table 3 and Table 4) present the average HDD and CDD for the study area for the period 2017-2022.

Table 3. HDD for the Greek pilot – monthly data (2017-2022 averages)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
North Athens	311.48	237.22	209.94	97.88	5.92	0.00	0.00	0.00	0.00	6.25	93.80	220.94	1183.42
West Athens	296.79	219.76	188.87	76.75	3.46	0.00	0.00	0.00	0.00	4.54	75.56	205.28	1071.01
Central Athens	285.52	215.84	187.43	84.77	3.21	0.00	0.00	0.00	0.00	2.80	76.39	192.63	1048.59
South Athens	278.35	209.72	180.89	80.61	2.43	0.00	0.00	0.00	0.00	1.85	71.26	184.81	1009.92
Piraeus region	256.96	185.16	155.33	54.18	0.66	0.00	0.00	0.00	0.00	1.33	45.97	165.79	865.38

Source: (Eurostat, 2023a)

Table 4. CDD for the Greek pilot – monthly data (2017-2022 averages)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
North Athens	0.00	0.00	0.00	0.03	11.48	97.48	194.17	199.23	71.41	3.77	0.00	0.00	577.56
West Athens	0.00	0.00	0.00	0.00	7.07	81.83	175.19	182.93	54.72	1.84	0.00	0.00	503.58
Central Athens	0.00	0.00	0.00	0.21	15.85	108.85	207.93	213.25	80.90	4.70	0.00	0.00	631.67
South Athens	0.00	0.00	0.00	0.00	8.25	93.41	188.37	199.18	70.93	3.25	0.00	0.00	563.38
Piraeus region	0.00	0.00	0.00	0.01	8.93	97.40	192.98	204.47	76.07	3.74	0.00	0.00	583.60

Source: (Eurostat, 2023a)

2.2 Population characteristics

With a population over three million (Table 5), the Athens Urban Area is the largest urban conglomeration in Greece, with high population density (Figure 34).

Table 5. Athens Urban Area permanent population – total and by gender (2021 Census)

Area	Permanent population	Men	Women	Men (%)	Women (%)
Central Athens	**1,002,212**	**480,844**	**521,368**	**48.0**	**52.0**
Athens Municipality	643,452	310,569	332,883	48.3	51.7
Bytonas Municipality	59,134	27,910	31,224	47.2	52.8
Galatsi Municipality	57,909	27,715	30,194	47.9	52.1
Dafnne - Ymittos Municipality	33,886	16,118	17,768	47.6	52.4
Zografou Municipality	69,874	32,790	37,084	46.9	53.1
Illioupoli Municipality	76,730	36,445	40,285	47.5	52.5
Kaisariani Municipality	26,269	12,488	13,781	47.5	52.5
Nea Philadelphia - Nea Chalkidona Municipality	34,958	16,809	18,149	48.1	51.9
North Athens	**601,163**	**283,332**	**317,831**	**47.1**	**52.9**
Maroussi Municipality	71,830	33,516	38,314	46.7	53.3
Agia Paraskevi Municipality	62,147	29,104	33,043	46.8	53.2
Vrilissia Municipality	32,417	15,410	17,007	47.5	52.5
Heraklion Municipality	50,494	24,084	26,410	47.7	52.3
Kifissia Municipality	72,878	34,400	38,478	47.2	52.8
Lykovrisi - Pefki Municipality	30,998	14,782	16,216	47.7	52.3
Metamorphosis Municipality	30,174	14,522	15,652	48.1	51.9
Nea Ionia Municipality	64,611	31,197	33,414	48.3	51.7
Papagos - Cholargos Municipality	45,266	20,651	24,615	45.6	54.4
Penteli Municipality	35,610	17,096	18,514	48.0	52.0
Filothei - Psychiko Municipality	27,636	12,530	15,106	45.3	54.7
Chalandri Municipality	77,102	36,040	41,062	46.7	53.3
West Athens	**478,883**	**232,872**	**246,011**	**48.6**	**51.4**
Peristeri Municipality	133,630	65,077	68,553	48.7	51.3
Agia Varvara Municipality	26,759	12,747	14,012	47.6	52.4
Agioi Anargyroi - Kamatero Municipality	61,462	30,219	31,243	49.2	50.8
Egaleo Municipality	65,831	32,014	33,817	48.6	51.4
Ilion Municipality	84,004	40,833	43,171	48.6	51.4
Petroupoli Municipality	60,146	28,999	31,147	48.2	51.8
Chaidari Municipality	47,051	22,983	24,068	48.8	51.2
South Athens	**529,455**	**249,415**	**280,040**	**47.1**	**52.9**
Kallithea	97,616	45,558	52,058	46.7	53.3
Agios Dimitrios Municipality	71,664	34,624	37,040	48.3	51.7
Alimos Municipality	43,174	20,499	22,675	47.5	52.5
Glyfada Municipality	89,597	42,257	47,340	47.2	52.8
Elliniko-Argyroupoli Municipality	50,027	23,758	26,269	47.5	52.5
Moschato - Tavros Municipality	39,661	19,178	20,483	48.4	51.6
Nea Smyrni Municipality	72,853	33,642	39,211	46.2	53.8
Palaio Faliro Municipality	64,863	29,899	34,964	46.1	53.9
Piraeus region	**448,051**	**216,823**	**231,228**	**48.4**	**51.6**
Piraeus Municipality	168,151	80,642	87,509	48.0	52.0
Keratsini - Drapetsona Municipality	89,536	43,247	46,289	48.3	51.7
Korydallos Municipality	61,248	30,257	30,991	49.4	50.6
Nikaia - Agios Ioannis Rentis Municipality	103,488	50,061	53,427	48.4	51.6
Perama Municipality	25,628	12,616	13,012	49.2	50.8

Source: (Hellenic Statistical Authority, 2023b)

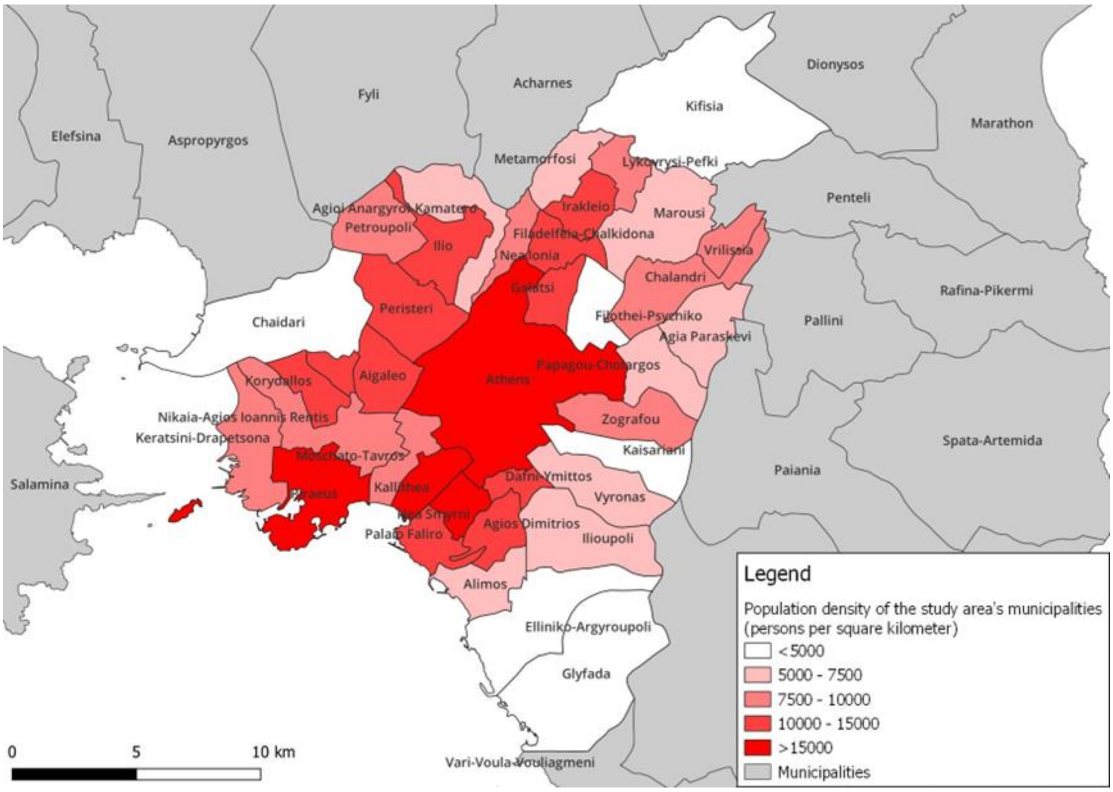


Figure 34. Population density in Athens Urban Area

About 48% are men and 52% are women. A worrisome finding is that the population of the Attica Region, and consequently of the pilot area, is ageing, as shown in Figure 35. In line with this fact, the share of one-person households (34.8% in total) has increased by around 37% and that of two-person households (27.4% in total) by 4%, while three-person (18.7% in total), four-person (14.6% in total) and five or more-person (4.6% in total) households have decreased by 2.3%, 10.7% and 9.9%, respectively (Hellenic Statistical Authority, 2023a).

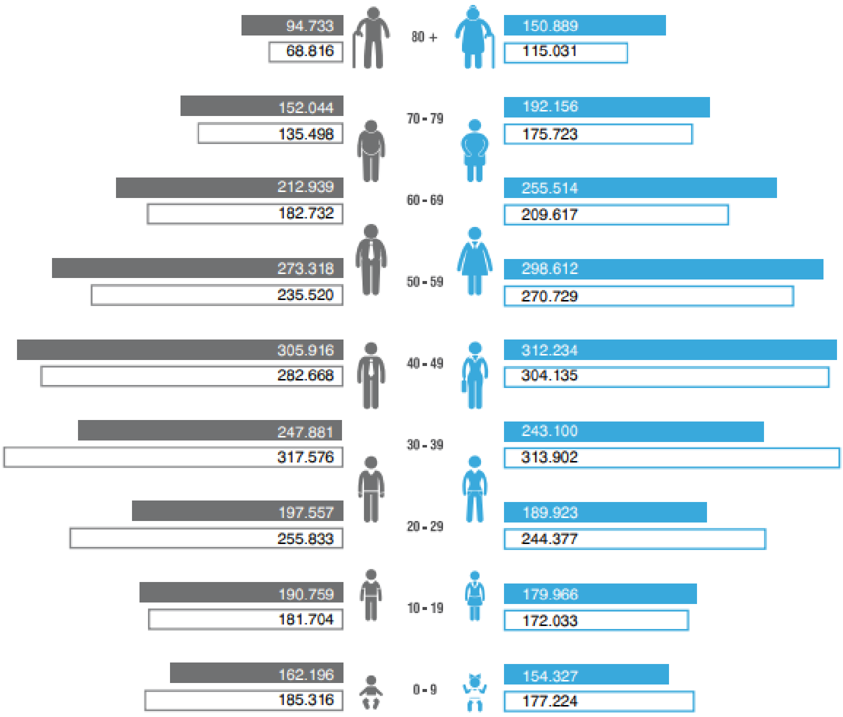


Figure 35. Permanent population by gender and age groups in the Region of Attica (Source: (Hellenic Statistical Authority, 2023a)

The Athens Urban Area is the political, economic, and maritime centre of Greece, with a large financial sector, and the port Piraeus, which is the largest passenger port as well as one of the largest container ports in Europe. In absolute terms, the Gross Domestic Product (GDP) of the Athens Urban Area was 65.95 billion € in 2020, accounting for about 40% of the whole Greek economic output. The GDP per capita was more than 21,500 € or 140% of the national average in the same year, and the unemployment rate stood at 14.2% (national unemployment rate: 16.3%). Detailed data for the years 2017-2021 are presented in Table 6 and Table 7. The richest regions are Central and North Athens and the poorest is West Athens, whereas South Athens and Piraeus region stand in the middle. Significant income inequalities are also observed within the Athens Urban Area regions. Compared to Central Athens, which is the richest region in the study area, the GDP per capita in North Athens is around 82%, in South Athens and Piraeus about 59%, and in West Athens only 35%.

Table 6. GDP per capita at current market prices in Athens Urban Area

	2017	2018	2019	2020	2021
Greece	16,400	16,700	17,100	15,500	17,000
Attiki	22,500	22,900	23,400	21,100	23,000
North Athens	26,800	26,800	28,000	25,700	--
West Athens	11,400	11,600	11,900	10,600	--
Central Athens	32,500	33,100	33,800	30,500	--
South Athens	19,100	19,500	20,100	18,100	--
Piraeus region	19,000	19,500	20,000	18,100	--

Source: (Eurostat, 2023b)

Table 7. GDP per capita in Athens Urban Area in relation to the national GDP per capita

	2017	2018	2019	2020	2021
Attiki	137.2%	137.1%	136.8%	136.1%	135.3%
North Athens	163.4%	160.5%	163.7%	165.8%	--
West Athens	69.5%	69.5%	69.6%	68.4%	--
Central Athens	198.2%	198.2%	197.7%	196.8%	--
South Athens	116.5%	116.8%	117.5%	116.8%	--
Piraeus region	115.9%	116.8%	117.0%	116.8%	--

Source: (Eurostat, 2023b)

2.3 Housing characteristics

The latest Greek Housing Census was conducted from July to October 2021, but the results have not yet been released. Therefore, the description of housing characteristics was based on the previous census, which was conducted in 2011, regarding the number of houses, the construction period and the size (number of rooms and size in m^2). The energy performance characteristics of the buildings, however, is based on the 2011 Greek Housing Census and the statistical results of the Energy Performance of Buildings Certificates, which are presented annual and quarterly basis for the Hellenic Territory by the Ministry of Environment and Energy (https://bpes.ypeka.gr/?page_id=21&stat=222).

Based on the 2011 Greek Housing Census, the total number of residences is around 1,662,500. About 37.6% are located in Central Athens, 17.2% in North Athens, 14.2% in West Athens, 16.6% in South Athens, and 14.4% in Piraeus region.

As far as the construction period is concerned (Table 8), 62% of the houses were built before the implementation of thermal requirements and energy-related building codes (before 1980). The area with the oldest houses is Central Athens (around 75% of the houses were built before 1981), followed by Piraeus region (about 62% of the houses were built before 1981). North Athens, on the other hand, shows the lowest percentage of old buildings (around 44.5%). West and South Athens lie in the middle, i.e., the pre- 1981 houses make up 58.6% and 54.6%, respectively.

Table 8. *Number of residences by construction period in Athens Urban Area*

	Total no. of houses	Construction period							
		Before 1945	1946 - 1960	1961 - 1970	1971 - 1980	1981 - 1990	1991 - 2000	2001 - 2005	After 2006
Central Athens	625,811	14,240	63,060	195,254	194,064	55,057	40,765	33,929	29,442
North Athens	286,087	3,967	16,006	28,309	79,096	60,976	49,486	25,511	22,736
West Athens	235,730	2,826	20,099	43,541	71,765	38,486	26,474	17,797	14,742
South Athens	275,396	2,945	15,112	44,066	88,305	47,716	36,603	21,424	19,225
Piraeus region	239,485	9,235	20,346	45,877	72,009	30,590	21,325	21,473	18,630

According to Table 9, 12.4% of dwellings are less than 50 m^2, 39.3% between 50 and 79 m^2, 32.5% between 80 and 109 m^2, and the rest (i.e., 15.8%) more than 110 m^2. Most of the houses in Central Athens are small and in North Athens large. In the other areas there is, more or less, a more even distribution of dwelling sizes (Figure 36).

Table 9. Number of residences by size (in m^2) in Athens Urban Area

Area	Total no. of houses	Area (m^2)									
		Less than 40	40 - 49	50 - 59	60 - 69	70 - 79	80 - 89	90 - 99	100 - 109	110 - 119	120+
Central Athens	625,811	55,298	53,683	103,738	72,136	109,834	80,539	52,799	38,668	20,602	38,514
North Athens	286,087	7,948	9,238	20,053	19,451	31,231	36,876	28,623	31,230	22,174	79,263
West Athens	235,730	11,334	14,202	26,494	28,438	40,740	40,893	28,109	20,072	9,488	15,960
South Athens	275,396	13,383	13,901	30,002	25,090	40,328	42,481	29,911	26,416	16,422	37,462
Piraeus region	239,485	11,670	15,695	29,922	31,830	43,854	40,173	25,529	17,260	8,719	14,833

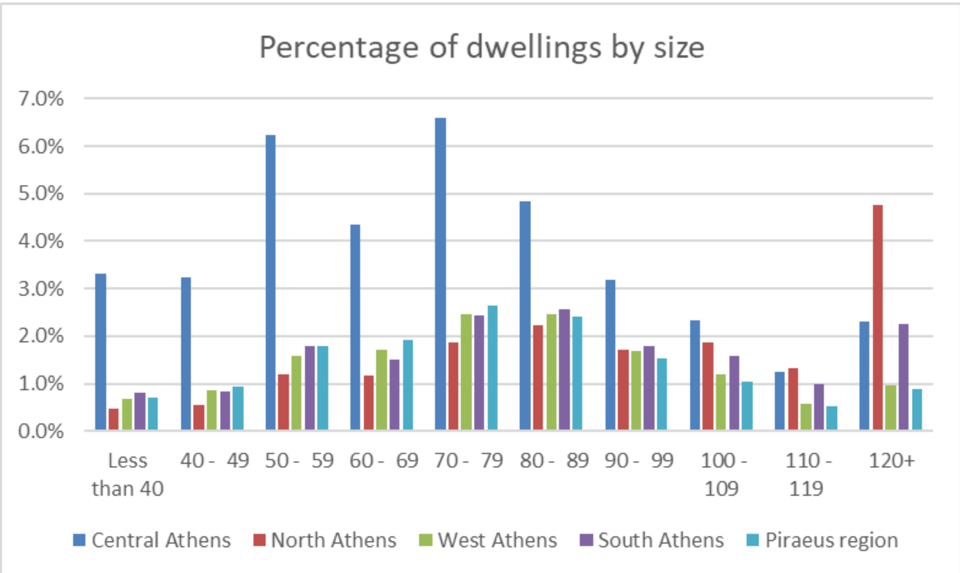


Figure 36. Distribution of dwellings by size and regions in Athens Urban Area

A similar pattern is observed relative to the number of rooms. Specifically, 6.6% of dwellings have one room (apart from the kitchen and bathroom), 26.7% have two rooms, 42% three rooms, 19.2% four rooms, and the rest 5+ rooms. Central Athens, as expected, has the highest percentage of small dwellings (one or two rooms), as well as of dwellings with three rooms out of the total number of dwellings (Figure 37).

Table 10. Number of residences by number of rooms in Athens Urban Area

	Total no. of houses	Number of rooms					
		1	2	3	4	5	6+
Central Athens	625,811	58,294	203,407	249,166	90,276	18,309	6,359
North Athens	286,087	9,644	47,525	110,734	84,549	21,758	11,877
West Athens	235,730	12,910	59,440	109,256	45,150	6,604	2,370
South Athens	275,396	15,133	64,859	117,940	61,125	12,210	4,129
Piraeus region	239,485	13,429	68,709	111,701	37,451	6,183	2,012

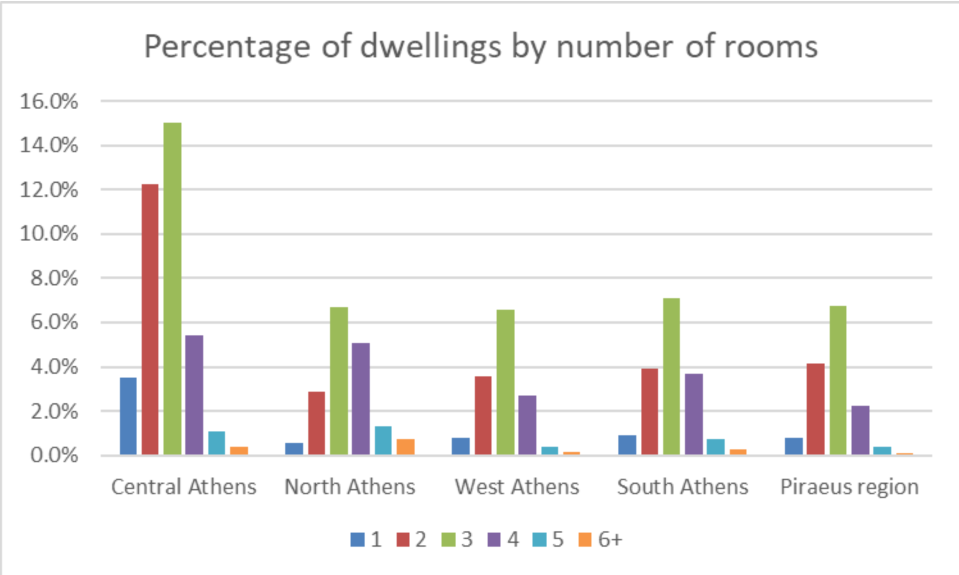


Figure 37. Distribution of dwellings by number of rooms and regions in Athens Urban Area

According to the results of the 2011 Housing Census, in the total of dwellings of the Athens Urban Area, 883,948 dwellings (53.2%) have some kind of insulation, while 778,561 dwellings (46.8%) have no insulation. Table 11 below shows the percentage of the type of insulation of the dwellings by regional area in the pilot. Specifically, 25.3% have double glazing windows, 9.9% have insulated walls/roofs, and 18% have two or more insulation types (e.g., double glazing windows and insulated walls).

Table 11. Number of houses by type of insulation in Athens Urban Area

	Total no. of houses	Energy efficiency measures			
		Double glazing	External wall insulation	Two or more insulation types	No insulation
Central Athens	625,811	139,497	64,473	69,405	352,436
North Athens	286,087	81,757	30,915	87,377	86,038
West Athens	235,730	63,411	20,212	46,495	105,612
South Athens	275,396	75,807	28,155	55,839	115,595
Piraeus region	239,485	60,907	20,168	39,530	118,880

In order to get a more recent picture of the energy efficiency situation of the dwellings in the area of interest, statistics from the Energy Performance of Buildings Certificates (EPBC) are presented below, which were retrieved from the Ministry of Environment and Energy (https://bpes.ypeka.gr/?page_id=21&stat=222). The analysis is based on more than 797,000 EPBCs issued in the period 2011-2021.

According to Table 12, about 62% of primary energy consumption is used for heating, 21.8% for domestic hot water (DHW), 16.2% for cooling and less than 0.01% for lighting. Moreover, only 0.02% of primary energy consumption is produced by RES.

Table 12. Average primary energy consumption (kWh/m²) by region, type of building and energy use in Athens Urban Area

	Heating	Cooling	Lighting	DHW	RES participation	Total primary energy consumption
Athens region	**151.10**	**39.51**	**0.00**	**53.21**	**0.05**	**243.77**
Apartment	147.16	38.52	0.00	53.70	0.03	**239.34**
SFH	256.85	64.33	0.00	44.51	0.21	**365.49**
MFH	138.81	43.64	0.00	38.03	0.94	**219.55**
Piraeus region	**157.88**	**42.13**	**0.00**	**52.37**	**0.03**	**252.34**
Apartment	143.75	39.89	0.00	52.34	0.01	**235.97**
SFH	310.84	65.94	0.00	53.27	0.17	**429.87**
MFH	192.03	50.31	0.00	48.75	0.28	**290.81**

As presented in Table 13, more than 71% of dwelling in the area of the Greek pilot are classified in the three worst energy classes (E, F and G), about 25% in the middle energy classes (C & D), and about 4% in the highest energy classes (A+ to B). It should be noted that some newly constructed dwellings are classified in low energy category E because the year of issue of the building permit was before the date of entry into force of the building insulation regulation issued in 2010 (known as KENAK), while their construction was completed in the period 2011-2021.

Table 13. Number of EPBCs by region, type of building and energy class

	Energy class									
	A+	A	B+	B	C	D	E	F	G	Total
Athens region	**877**	**1,666**	**5,866**	**16,786**	**66,205**	**84,445**	**90,361**	**130,300**	**210,848**	**607,354**
Apartment	599	1,210	4,856	15,362	63,886	81,322	87,802	127,389	196,814	**579,240**
SFH	39	124	436	732	1,817	2,609	2,104	2,361	11,970	**22,192**
MFH	239	332	574	692	502	514	455	550	2,064	**5,922**
Piraeus region	**34**	**140**	**758**	**2,716**	**10,237**	**11,455**	**12,338**	**16,866**	**34,372**	**88,916**
Apartment	20	104	637	2,498	9,923	10,921	11,636	15,928	29,039	**80,706**
SFH	10	9	79	151	229	431	589	817	4,766	**7,081**
MFH	4	27	42	67	85	103	113	121	567	**1,129**
Total	**911**	**1,806**	**6,624**	**19,502**	**76,442**	**95,900**	**102,699**	**147,166**	**245,220**	**696,270**

Of particular interest are the following tables (Table 14 and Table 15), which analyse the results of the energy upgrading of houses that participated in the programmes “Exoikonomo I and II”, “Exoikonomo – Autonomo” and “Exoikonomo 2021”. In these dwellings, it is observed that the largest percentage, after the energy interventions, is classified in energy categories C, D and E. From the year 2021, the energy interventions lead to dwellings in energy categories B to A+ (Hellenic Ministry of Environment and Energy, 2022).

From all these figures, it is worth noting the energy saving potential of the three lowest energy classes (E, F and G), which ranges from 21% (when houses are upgraded by a maximum of one energy class) to around 96% (when they are upgraded to the highest energy class).

Table 14. Average annual energy consumption (kWh/m^2) of residential buildings by energy category before and after energy interventions

Before (S1)	After (S2)																	
	A+		A		B+		B		C		D		E		F		G	
	S1	S2	S1	S2	S1	S2	S1	S2	S1	S2	S1	S2	S1	S2	S1	S2	S1	S2
B					90.40	89.85												
C	173.50	19.60	192.61	63.29	159.32	119.26			147.40	144.04								
D	238.24	26.31	217.75	56.89	221.51	114.48	223.42	85.74	219.76	148.29	237.30	163.19						
E	224.84	19.90	260.30	52.83	265.87	111.49	273.23	83.49	260.61	148.70	261.39	192.02	289.92	212.60				
F	368.42	20.65	319.13	51.98	325.05	110.08	328.49	81.35	311.01	147.95	300.24	188.64	297.93	232.74	339.46	267.09		
G	512.95	22.08	522.38	51.57	556.02	117.74	570.95	85.22	516.94	157.55	491.82	202.48	477.31	250.01	476.52	300.79	627.49	435.23

Table 15. Energy savings after energy interventions

Before (S1)	A+	A	B+	B	C	D	E	F	G
	S2	S2	S2	S2	S2	S2	S2	S2	S2
B			-0.6%						
C	-88.7%	-67.1%	-25.1%		-2.3%				
D	-89.0%	-73.9%	-48.3%	-61.6%	-32.5%	-31.2%			
E	-91.1%	-79.7%	-58.1%	-69.4%	-42.9%	-26.5%	-26.7%		
F	-94.4%	-83.7%	-66.1%	-75.2%	-52.4%	-37.2%	-21.9%	-21.3%	
G	-95.7%	-90.1%	-78.8%	-85.1%	-69.5%	-58.8%	-47.6%	-36.9%	-30.6%

2.4 Energy poverty and vulnerability

The analysis in the area of the Athens Urban Area pilot regarding the current situation of energy poverty was based on data from Eurostat's EU SILC and HBS surveys, which were retrieved by the Hellenic Statistical Authority. The EU SILC and HBS survey microdata (at household level) were provided for the years 2017-2021. From the dataset, the observations selected were those that referred to region EL30 (variable DB040) and degree of urbanization 1 (variable DB100 - cities/densely populated area).

As regards the EUSILC indicators, according to Figure 38, the share of population living in a dwelling with a leaking roof, damp walls/floors/foundation within the Greek pilot area is lower than the national share (by 1.3%), as also has been the case since 2017, without significant differences over the years. The share of population not being able to keep their home adequately warm is slightly lower than the national level (by 0.8%) (Figure 39). Similar conclusions are drawn for the share of population having arrears on utility bills, which is also lower than the respective national share (by 5.1%), and follows the same trend since 2017, with both the rates of the pilot-area level and the national level decreasing over time (Figure 40). The differences between the shares of the pilot area and the national level do not follow a consistent pattern, yet both the EP rates of the pilot area and the national level are decreasing over time.

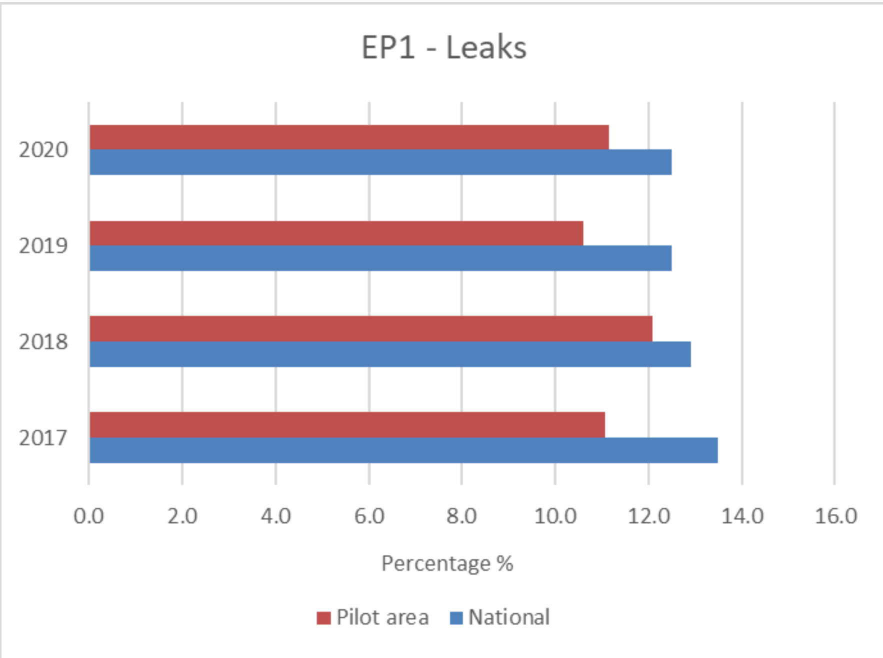


Figure 38. Share of total population living in a dwelling with leaks

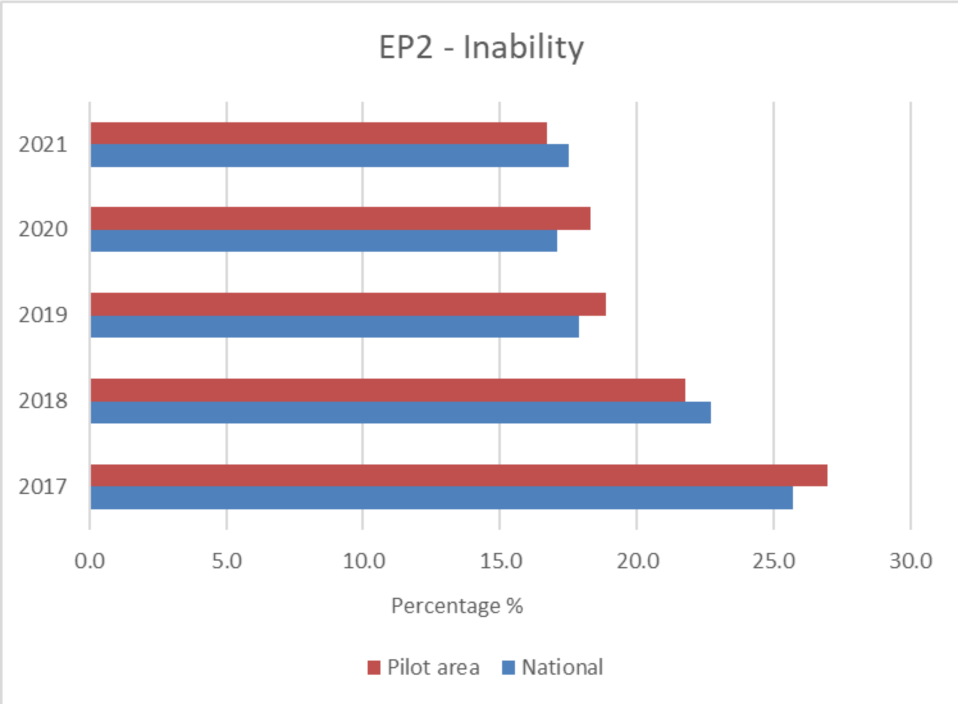


Figure 39. Share of population not able to keep home adequately warm

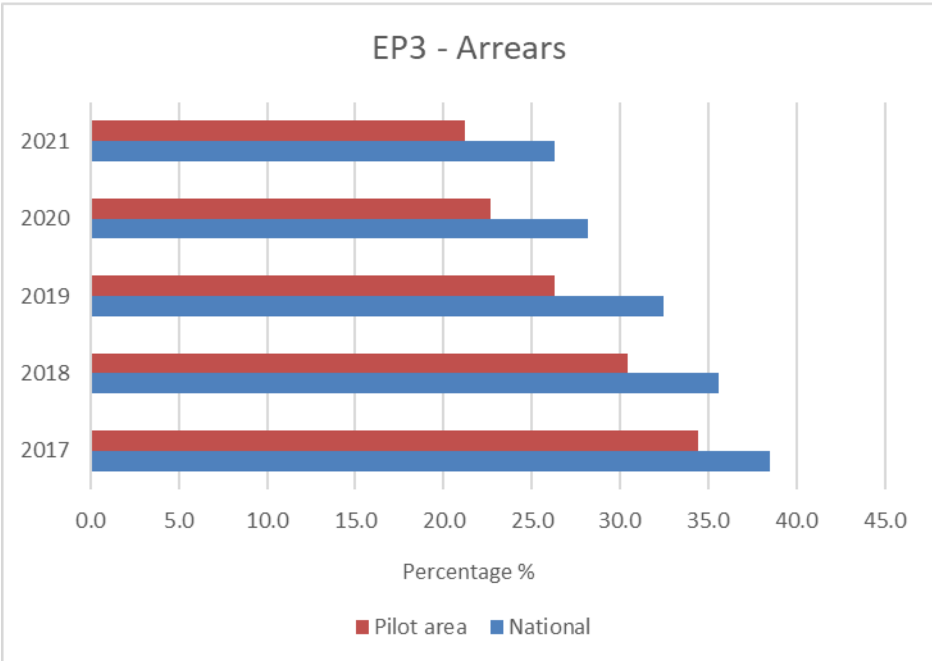


Figure 40. Share of population having arrears on utility bills

The rest EP indicators (i.e., EP4 to EP12) were examined only at the level of the pilot area, as not being official indicators. According to Figure 41, the share of population with arrears on utility bills only once has been constantly decreasing since 2017 (a decrease of 42% was marked between

2017 and 2021). The same happens for the share of population with arrears on their bills twice or more, with a reduction of 37% within the same years (Figure 42).

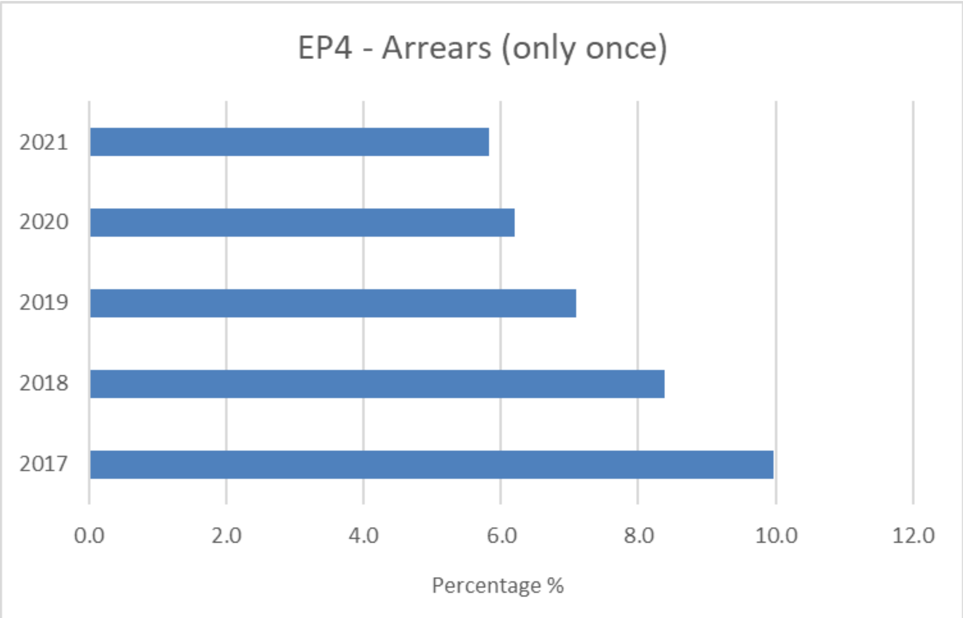


Figure 41. Share of population having arrears on utility bills only once in the past 12 months

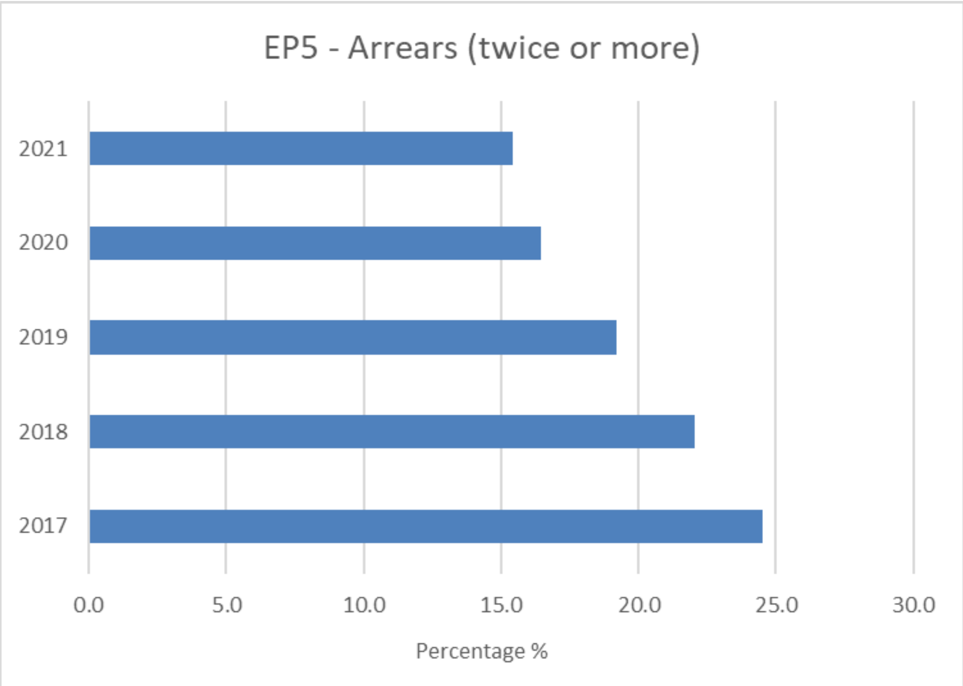


Figure 42. Share of population having arrears on utility bills twice or more in the past 12 months

The relative improvement in terms of EP issues is also apparent in the results of the Weighted Composite Indices. According to Figure 43, the share of population not experiencing EP issues increased from 50.3% in 2017 to 63.3% in 2020, whereas the share of those experiencing severe EP issues (i.e., the WCI1 equals to 1) dropped by just 0.5%. Similar conclusions are reached for the other two indices (WCI2 and WCI3), with the share of population without EP issues marking an increase over the last four years (Figure 44 and Figure 45, respectively).

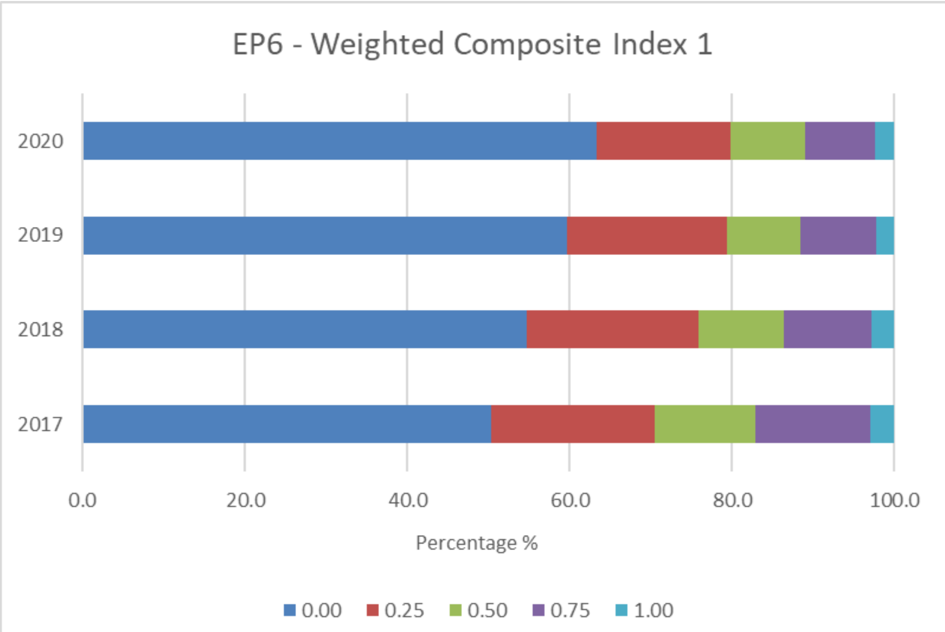


Figure 43. Share of population at EP according to WCI1

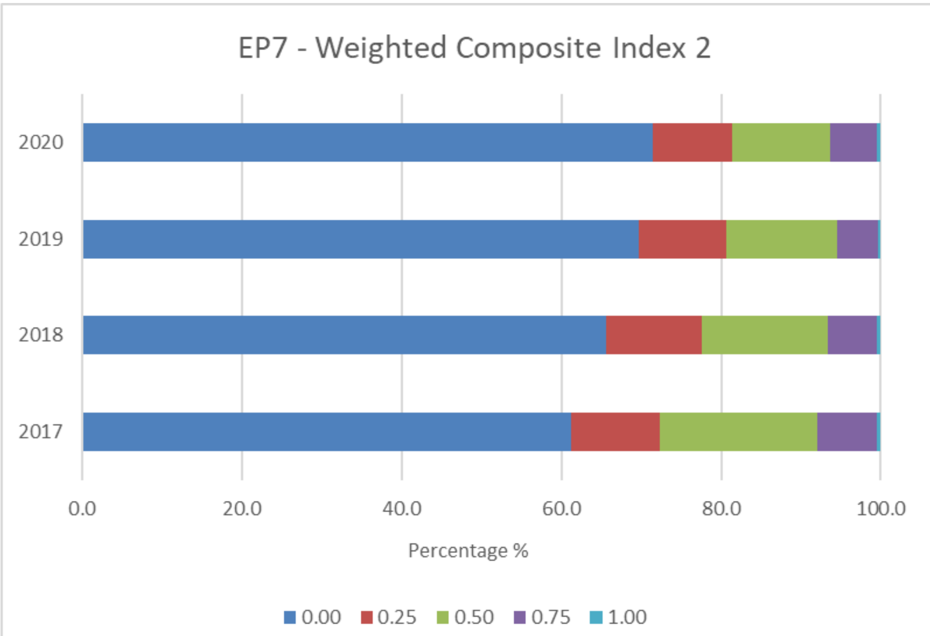


Figure 44. Share of population at EP according to WCI2

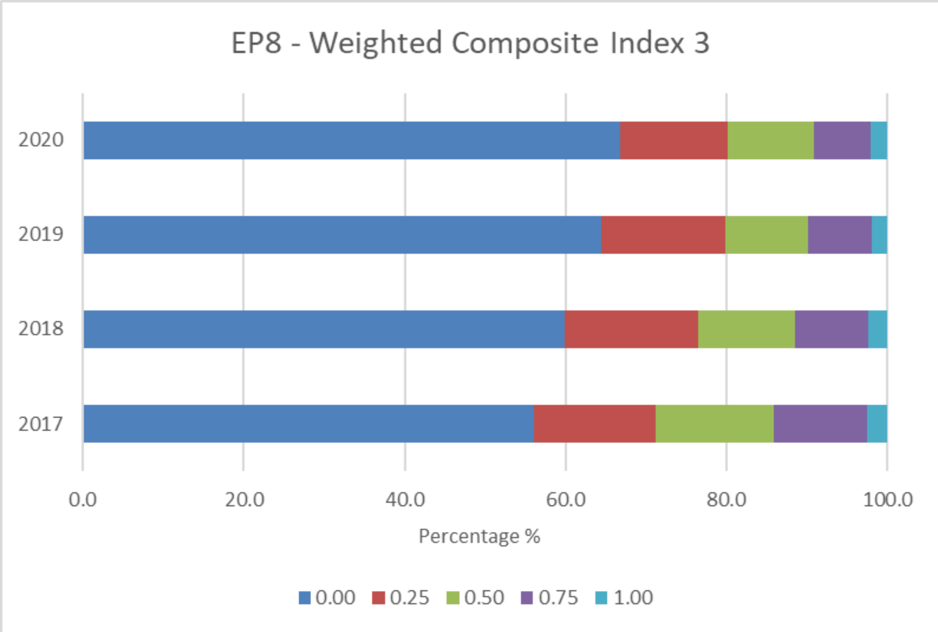


Figure 45. Share of population at EP according to WCI3

The Simple Composite Indices (SCI) follow a pattern similar to the Weighted Composite Indices analysed above, reflecting an overall improvement in EP issues. In all SCIs (Figure 46, Figure 47 and Figure 48), the share of population not experiencing EP issues is increasing, while the rest classes of population experiencing more important EP problems do not present significant changes over time. For example, SCI1 presents an increase from 50.3% to 63.3% between 2017 and 2020 for class 0 (population not experiencing EP issues), with the rest classes remaining almost stable over the years.

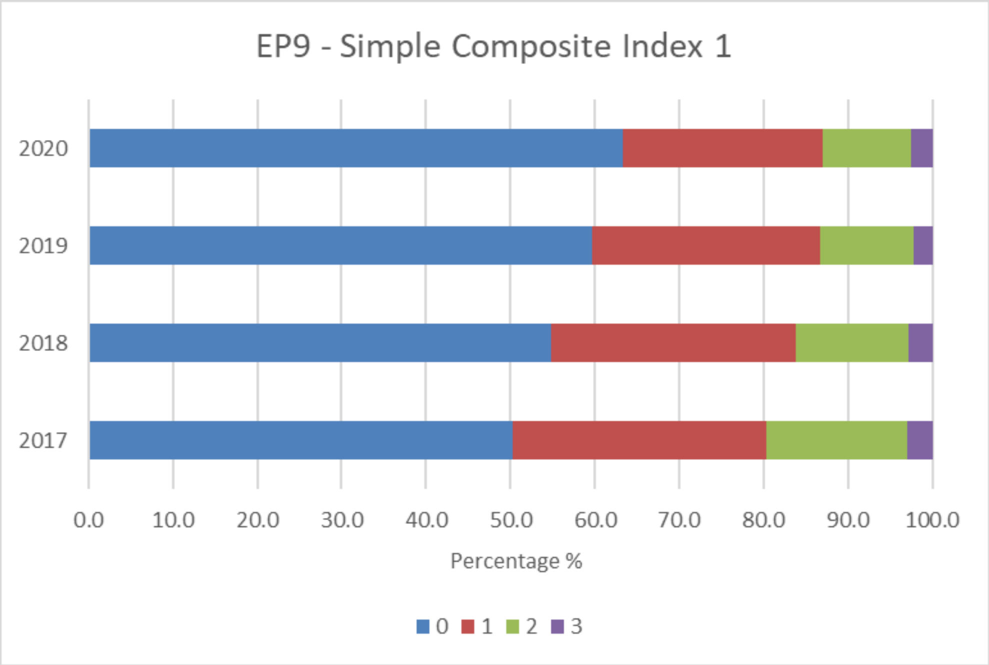


Figure 46. Share of population at EP according to SCI1

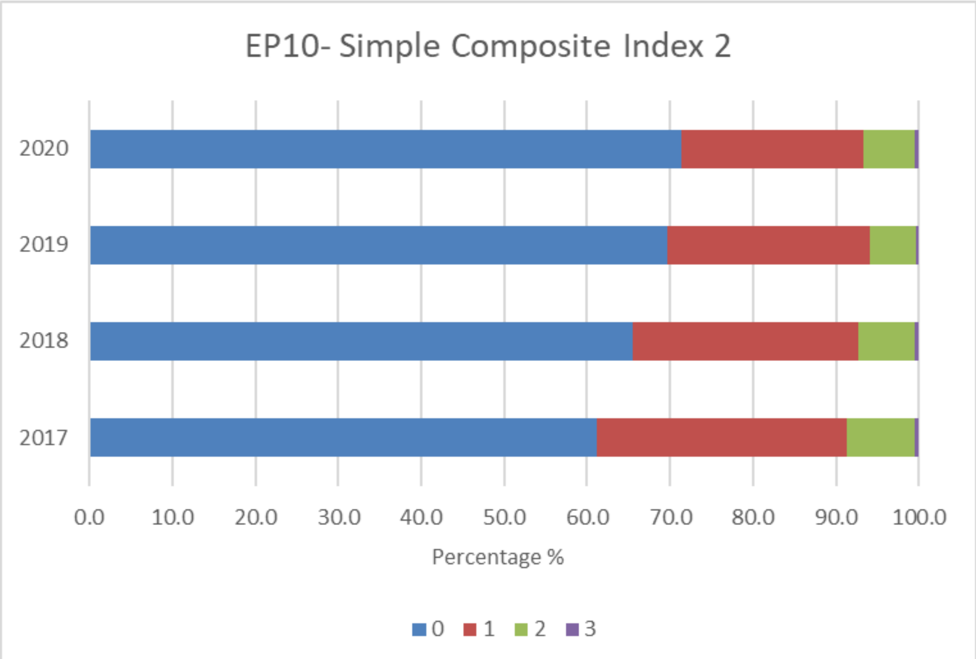


Figure 47. Share of population at EP according to SCI2

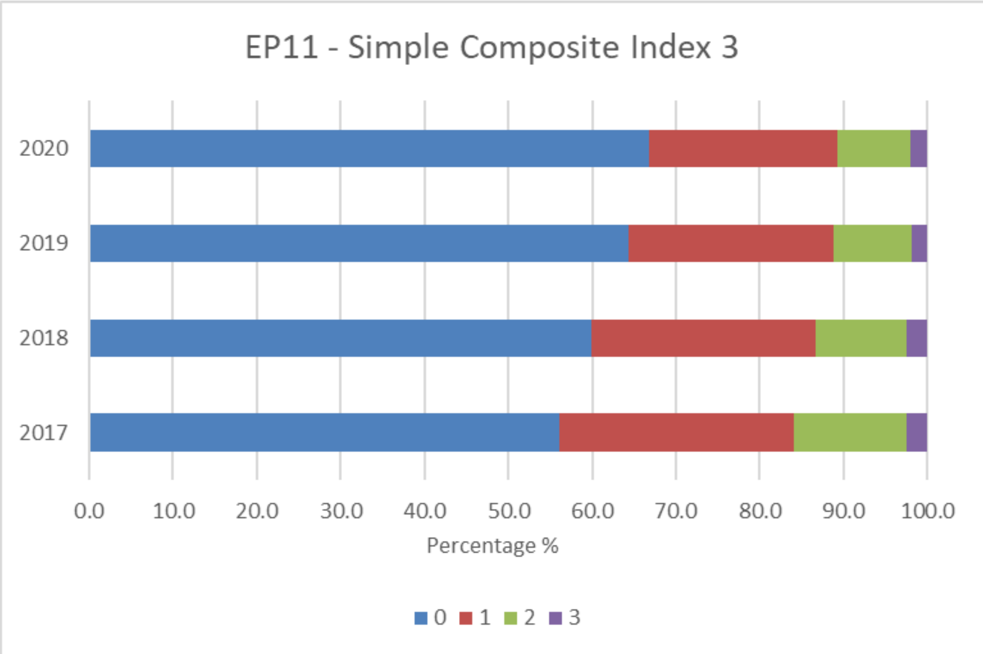


Figure 48. Share of population at EP according to SCI3

Finally, the percentage of population experiencing any type of EP, i.e., arrears on utility bills, inability to keep their house adequately warm, or leaks/damp walls, has been constantly decreasing since 2017 (Figure 49). More precisely, a reduction of 26% was marked between 2017 and 2020. This kind of indicator presents high rates, as practically combining all single EP indicators.

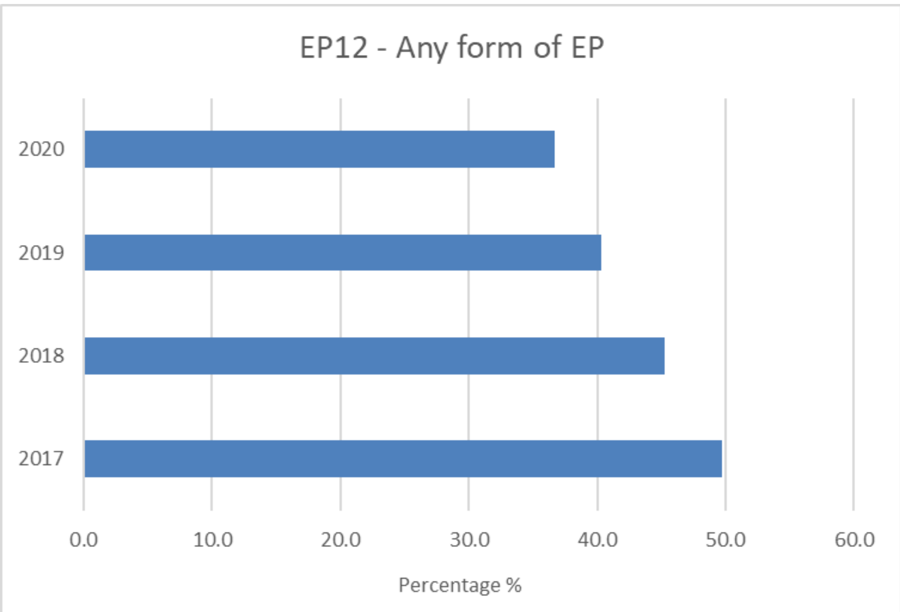


Figure 49. Share of population at EP according to EP12

Below, the EP indicators are investigated with respect to certain housing features and living conditions to explore the effect of the last ones on EP vulnerability in the pilot area. As shown in Figure 50, households living in detached and semi-detached or terraced houses are more prone to almost all EP indicators (arrears, leaks, inability to keep home warm), with a focus on the problem of leaks, probably due to the more indoor-outdoor spaces and open-to-air walls of these buildings, which makes it difficult to heat sufficiently a building.

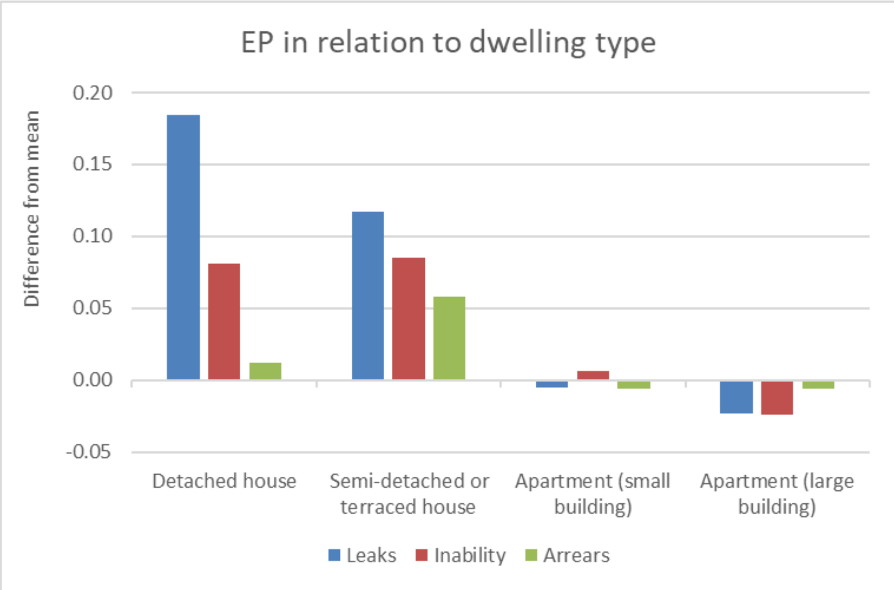


Figure 50. Leaks, inability to keep house warm and arrears on utility bills in relation to dwelling type

The relationship of EP indicators with the dwelling size is illustrated in Figure 51. Households living in one- or two-room houses present higher EP rates compared to the average, i.e., there appear mainly problems with leaks, followed by arrears and inability to keep home warm, while households living in houses with four or more rooms have lower EP rates.

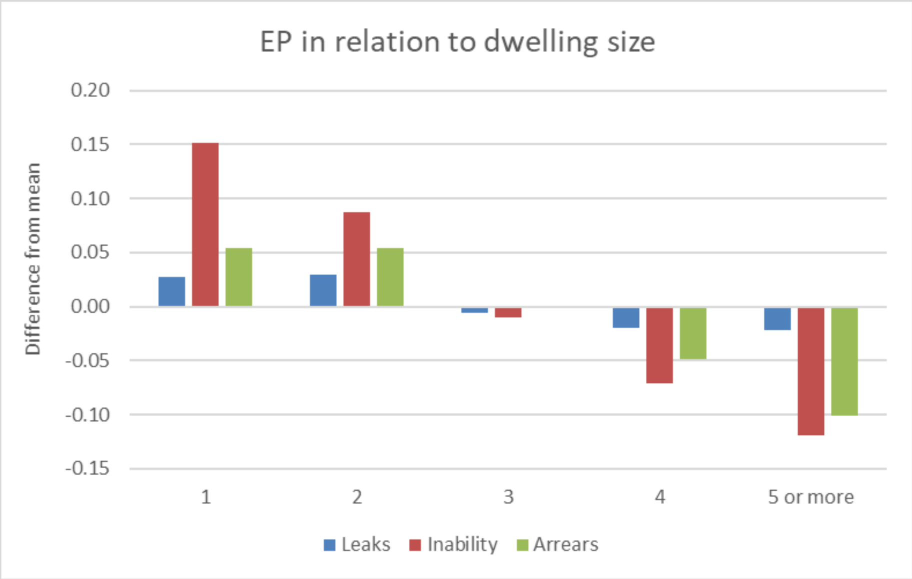


Figure 51. Leaks, inability to keep house warm and arrears on utility bills in relation to dwelling size

As regards tenure status, the most vulnerable groups to EP are tenants (mainly those at reduced rate, followed by those at market rate) (Figure 52).

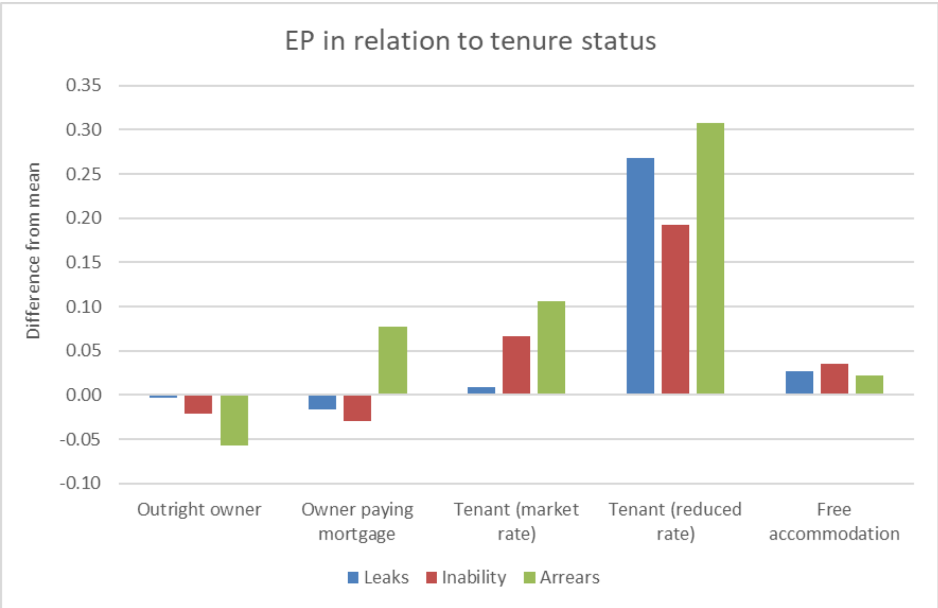


Figure 52. Leaks, inability to keep house warm and arrears on utility bills in relation to tenure status

Figure 53 shows that households experiencing great difficulty in making ends meet face also higher EP issues, with differences in EP rates of up to 21% compared to average rates. On the other hand, households that can easily make ends meet present quite lower EP rates, of up to 29% versus average rates.

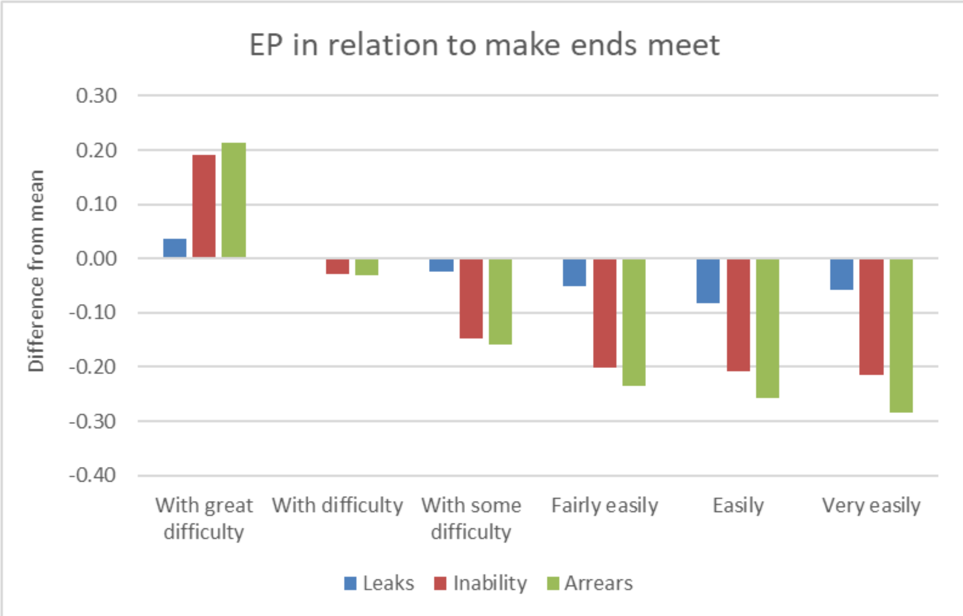


Figure 53. Leaks, inability to keep house warm and arrears on utility bills in relation to the level of difficulty in making ends meet

Similar trends are detected when examining the complementary EP indicators. More specifically, the highest EP rates compared to average are shown in the case of households living in detached and semi-detached or terraced houses (Figure 54), in the case of those living in one- or two-room homes (Figure 55), in the case of tenants at reduced rates (Figure 56) and, finally, in the case of those with great difficulty in making ends meet (Figure 57).

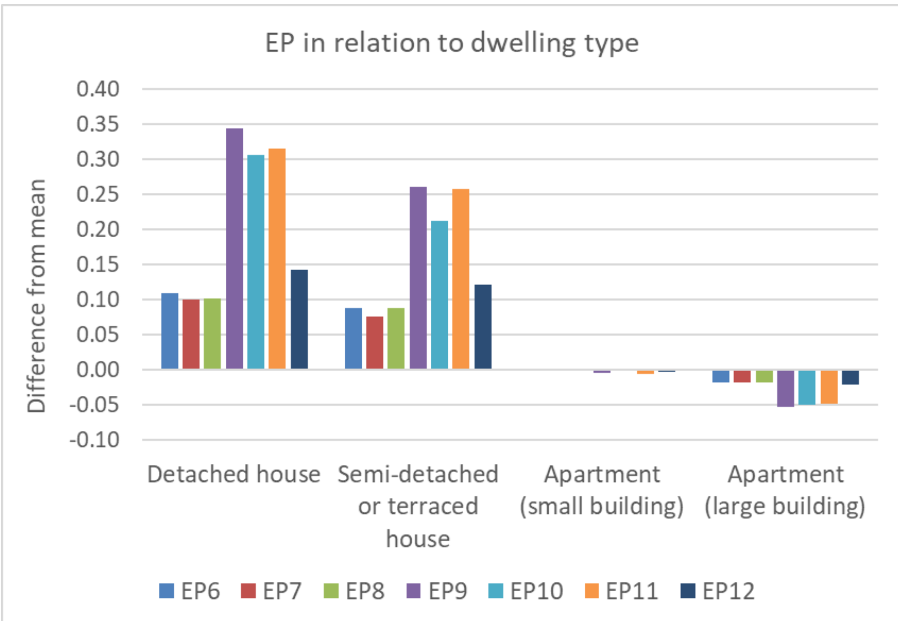


Figure 54. Complementary EP indicators in relation to dwelling type

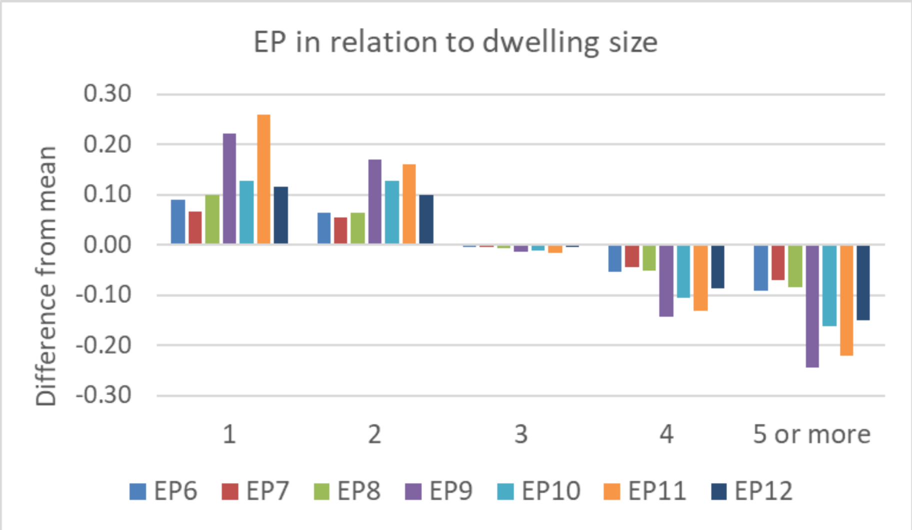


Figure 55. Complementary EP indicators in relation to dwelling size

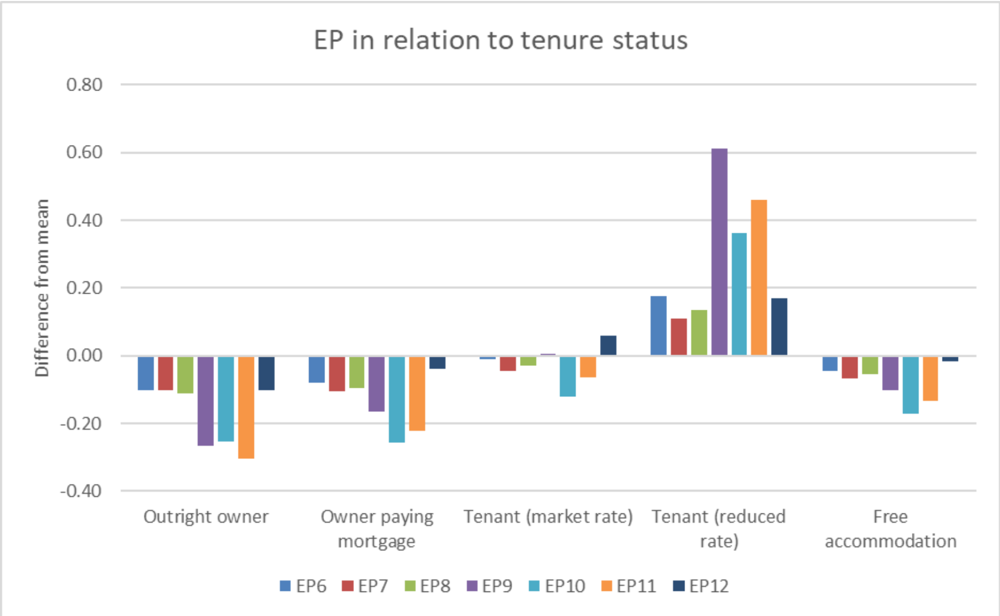


Figure 56. Complementary EP indicators in relation to tenure status

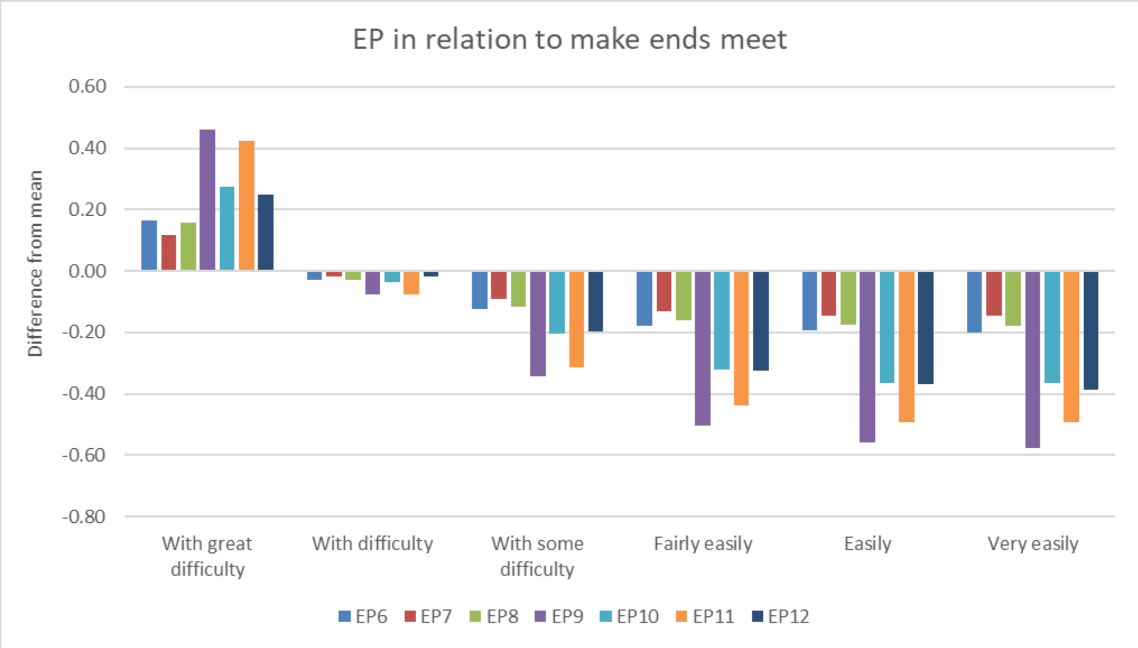


Figure 57. Complementary EP indicators in relation to the level of difficulty in making ends meet

The expenditure indicators, which were calculated based on the HBS data, are presented in Figure 58. Considering the **2M index**, the estimated levels of EP are very low (3-5%), which is largely attributed to the fact that the index does not count as energy poor households that under-consume energy, a situation quite common in Greece during the last decade, due to shrinking incomes and high energy prices. With the **M/2 index**, energy poverty levels were calculated between 11% and 16% in the period 2017-2021. Nevertheless, this index shows also significant weaknesses as it may classify as EP, households whose energy costs are low because they live in homes with high energy efficiency, while at the same time does not consider as EP, households with high energy expenditures, though necessary in order to ensure adequate internal thermal conditions in the dwellings.

With the national index (**NEPI**), the levels of energy poverty were estimated at levels of 9-11% in the reference period. It is worth mentioning that the structure of the NEPI incorporates key dimensions of the EP problem, namely, the discrepancy between consumed and required energy in order to ensure adequate internal thermal conditions in homes as well as households' income. However, a key point of criticism for the NEPI is the ambiguity in defining the minimum required energy consumption that is used in developing the condition (i) of the adopted definition. In addition, the identification of energy poor households requires a complex calculation process and particularly the calculation of the minimum required energy consumption of the residence, which obviously depends on its characteristics, the level of thermal insulation, the climatic conditions, etc.

Aiming to overcome these problems, two additional energy poverty indicators were formulated in the context of this analysis, namely the **modified NEPI** index, and the **modified LIHC** index. The estimated energy poverty levels for the Greek pilot based on the two new energy poverty indicators, are also shown in Figure 58, and were found to range from 9-11% with the **modified NEPI** index and between 22-26% with the **modified LIHC**.

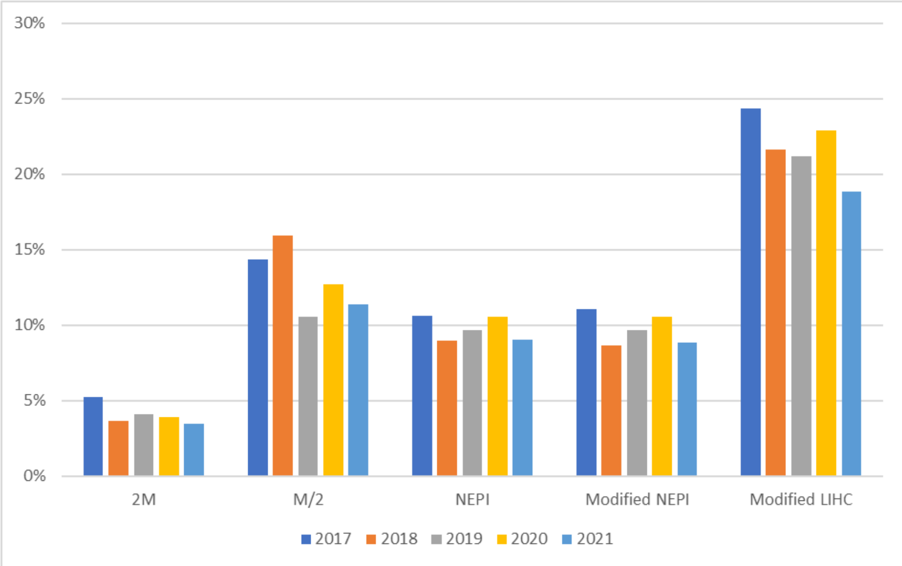


Figure 58. EP levels in the Greek pilot based on five different expenditure indicators for the period 2017-2021

All the aforementioned EP indicators take into account various aspects of the problem, by integrating individual conditions and adopting specific thresholds in order to characterize a household as energy poor. Changing these thresholds, the estimated levels of energy poverty in a region may be significantly influenced. For example, both the NEPI and the modified NEPI require that a household's equivalised annual net income be less than 60% of the median equivalised income of all households, according to the national definition of relative poverty. In other words, according to these indicators, a prerequisite for a household to be energy poor is to be classified below the official poverty levels. Figure 59 and Figure 60 show indicatively how EP levels based on NEPI and the modified NEPI indexes change, by altering the thresholds of the corresponding conditions they incorporate. For example, by using modified NEPI index and increasing the levelised income threshold to 80% of the median of the corresponding income for all households, which essentially indicates that households above the poverty level may also suffer from energy poverty, the EP rates in the area of interest almost double at 18-20% for the reporting period.

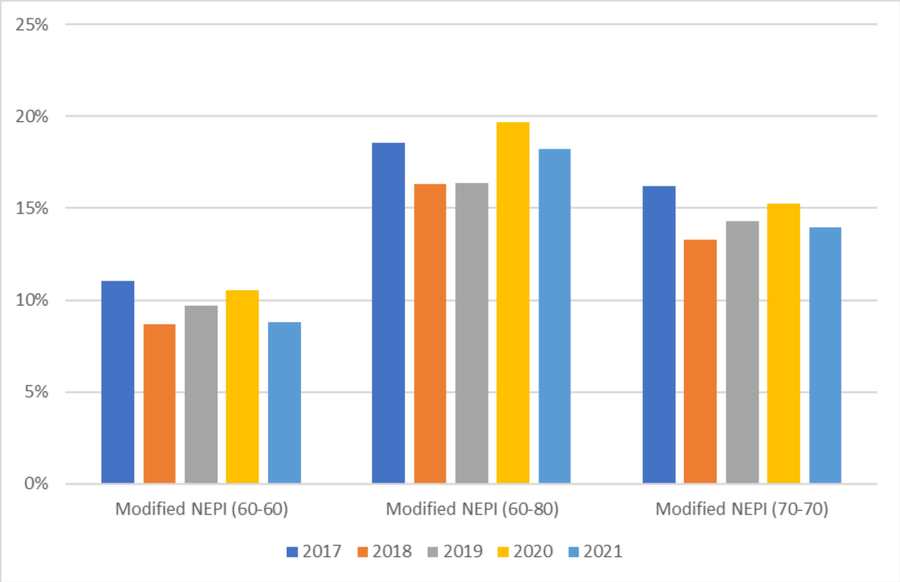


Figure 59. Estimated EP levels based on the modified NEPI index, adopting different thresholds for the two conditions used to structure the index. Condition (i): the threshold of the real in relation to theoretical energy expenditures is set to 60% or 70%. Condition (ii): the threshold of the levelized income in relation to national median is set to 60%, 70% or 80%

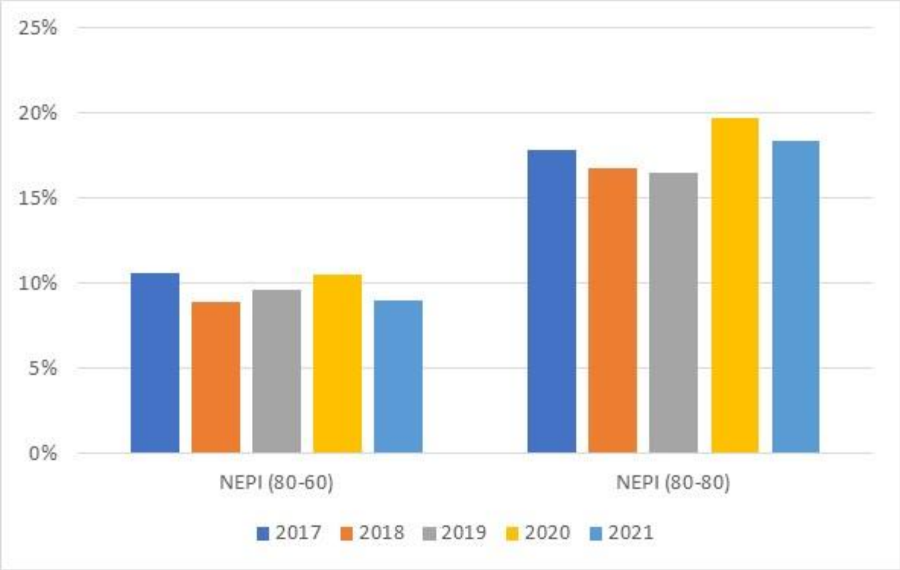


Figure 60. Estimated EP levels based on the NEPI index, for two different levels of the threshold used to control the condition (ii) of the index. Specifically, in the two scenarios examined the threshold of the levelized income in relation to national median is set to either 60% or 80%

For all five expenditure EP indicators calculated by HBS data, it is examined how certain housing characteristics and living conditions of households influence the estimated levels of energy poverty.

As can be seen in Figure 61, EP levels are lower in households that live in apartments compared to those that live in detached or semi-detached houses. This is probably attributed to the fact that apartments generally have lower energy losses than single-family houses, and thus they require relatively lower expenditures to ensure adequate thermal comfort conditions. This is also consistent with the results of EPBCs (Table 12). In addition, all indicators examined show that EP levels are lower in small apartment buildings. This probably has to do with the fact that the residents of relatively small multi-family buildings can more easily communicate with each other and agree to operate the central heating system that these buildings usually have. On the contrary, such an agreement is more difficult to achieve in large buildings with many occupants, which leads every household to look for alternative and usually inefficient ways of heating.

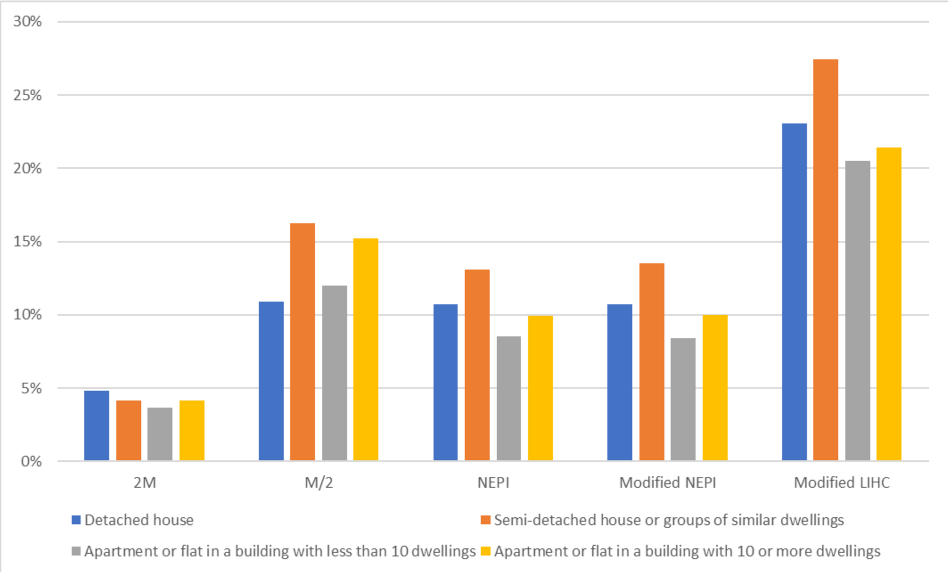


Figure 61. Estimated EP levels using the expenditure indicators in relation to dwelling type

As expected, households that pay rent for their housing show higher levels of EP than households that live in owner-occupied housing according to all EP indicators considered (Figure 62). It is also noteworthy that according to both NEPI and modified NEPI indices, the highest levels of EP occur in households, in which accommodation is provided for free by family or third parties. These are probably young families, at the beginning of their working life, with low incomes and perhaps high levels of unemployment.

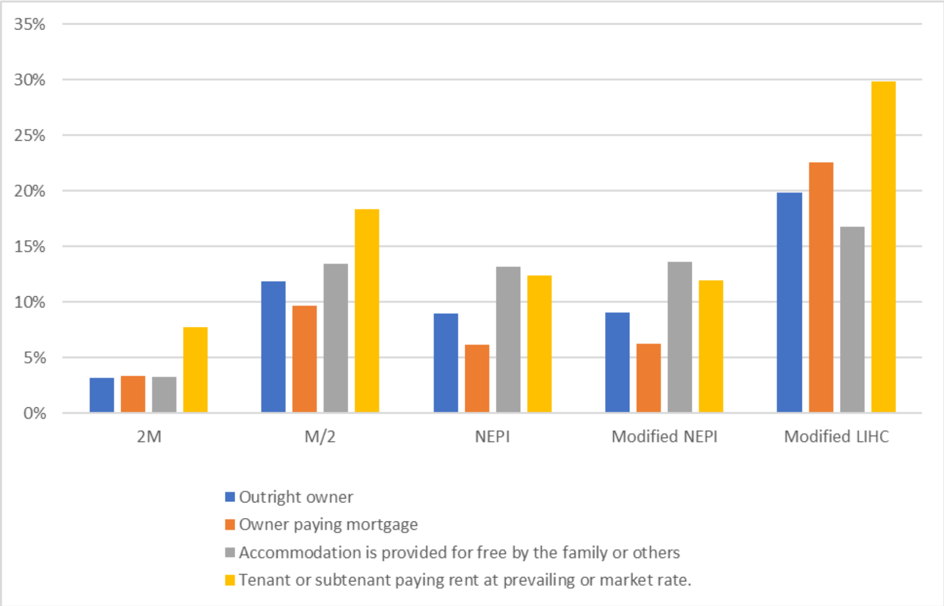


Figure 62. Estimated EP levels using the expenditure indicators in relation to tenure status

As a general trend, EP levels are higher in households living in small houses with a relatively small number of rooms (Figure 63Figure 75). This is probably attributed to the fact that low-income households usually live in small-sized houses with a limited number of rooms. However, two of the examined indicators show an increase in EP levels in households living in residences with many rooms, demonstrating the high energy costs required in order to ensure adequate thermal comfort conditions in these dwellings.

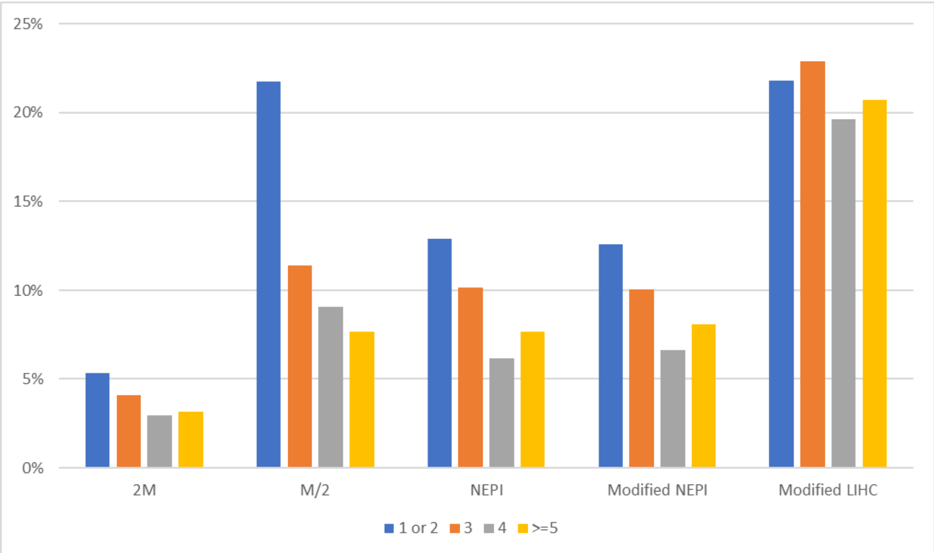


Figure 63. Estimated EP levels using the expenditure indicators in relation to the size of the dwellings and the number of rooms

Figure 64 clearly shows that EP is directly linked to the year of construction of the households' residence and therefore to their energy performance. Specifically, based on all indicators examined (except 2M) the EP levels are significantly reduced in households living in dwellings built after 1980, when the first national Thermal Insulation Regulation came into force. As regards the EP levels of households living in houses built after 1980, they are affected both by the continued improvements in the energy performance of buildings as well as by the increases in the surface area of new homes. In any case, improving the energy efficiency of the building stock is a basic condition for structurally addressing the problem of energy poverty. Finally, as clearly depicted in

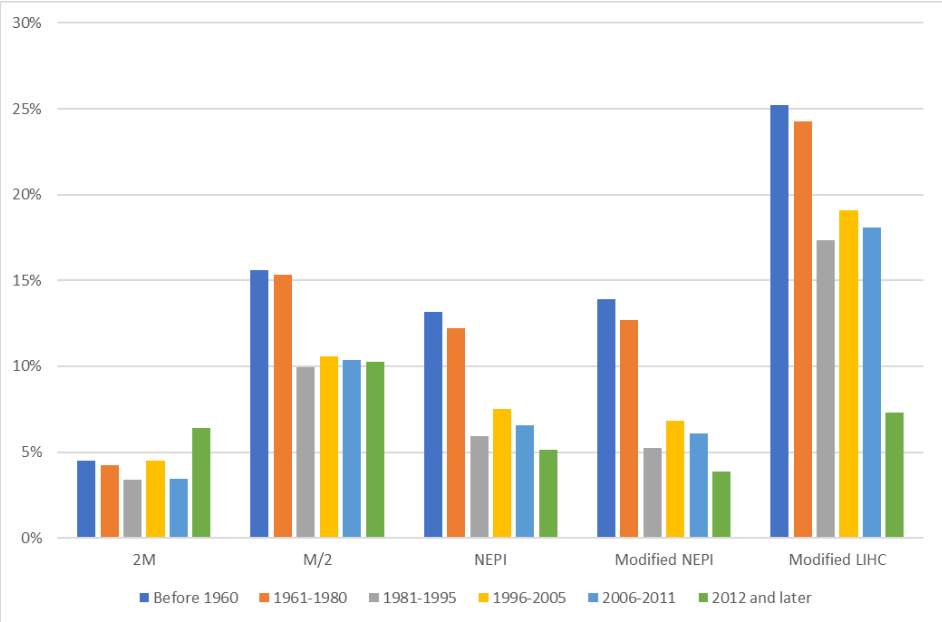


Figure 64. Estimated EP levels using the expenditure indicators in relation to the construction year of the dwelling

Figure 65, the problem of EP is affected to a large extent by households' income. Specifically, the NEPI as well as the modified NEPI and the modified LIHC indicators clearly show that more than 2/3 of households belonging to the lowest income categories are characterized as energy poor.

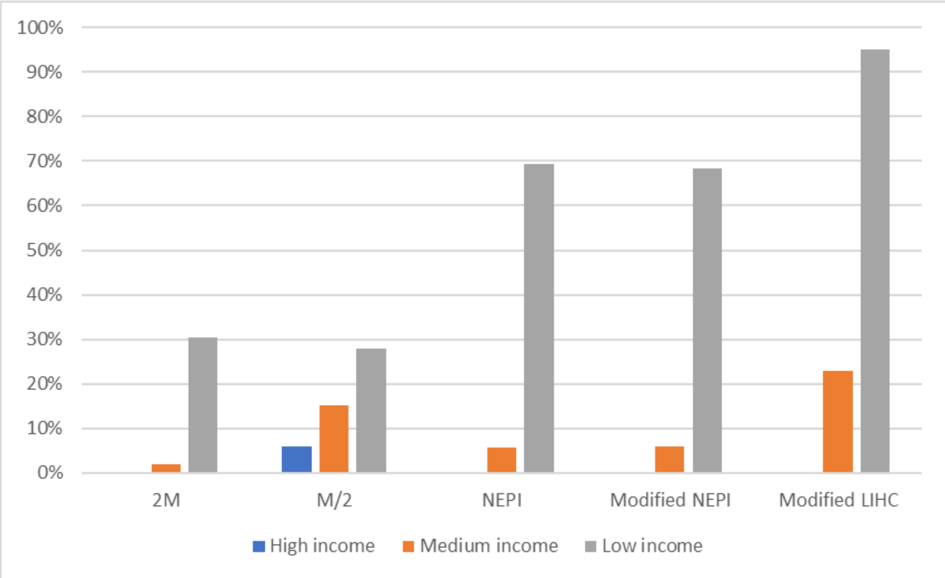


Figure 65. Estimated EP levels using the expenditure indicators in relation to income class of the households

3 Pilot 3 - Riga (Latvia)

3.1 Area characteristics

The capital of Latvia, Riga, founded in 1201, is located in the central part of Latvia, on the southern coast of the Gulf of Riga of the Baltic Sea. Although the area of the city of Riga occupies only 0.5% of the total area of Latvia, the city is home to a third of the total population of Latvia, making it the largest city at the level of both Latvia and the Baltic States.

The territory of Riga city municipality is divided into:

- **6 administrative territorial units**: Centre district, Kurzeme district, Northern district, Vidzeme suburb, Latgale suburb, Zemgale suburb;
- **58 neighbourhoods** (see Figure 66).

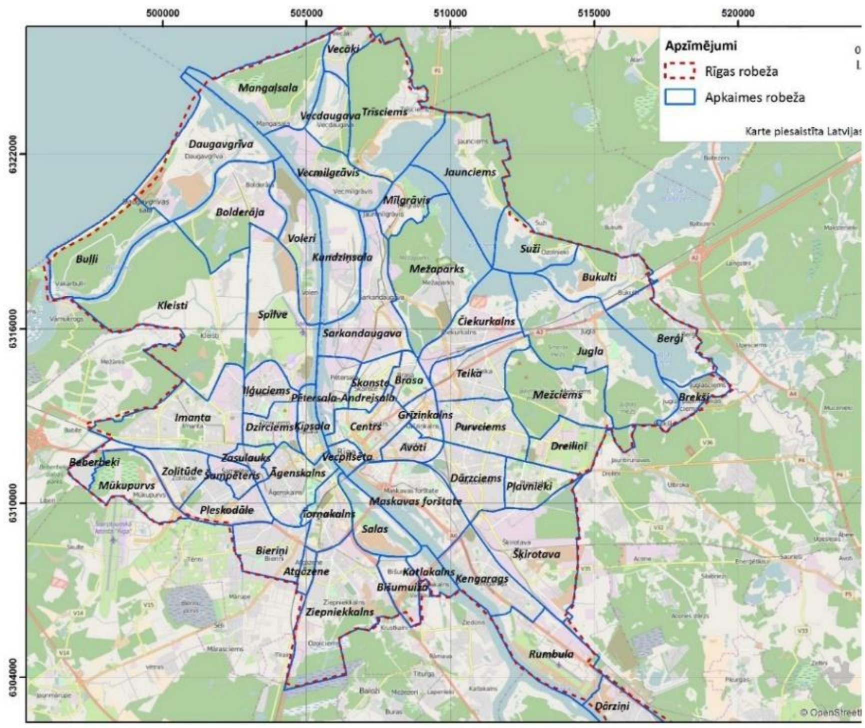


Figure 66. Map of Riga neighbourhoods

Riga has a high share of green areas. According to the Riga Territorial Plan for 2030, the city is characterized by 41% of natural areas, of which 16% of waters and 25% of greenery and natural areas. The average monthly outdoor air temperature in Riga is summarizes in Figure 67.

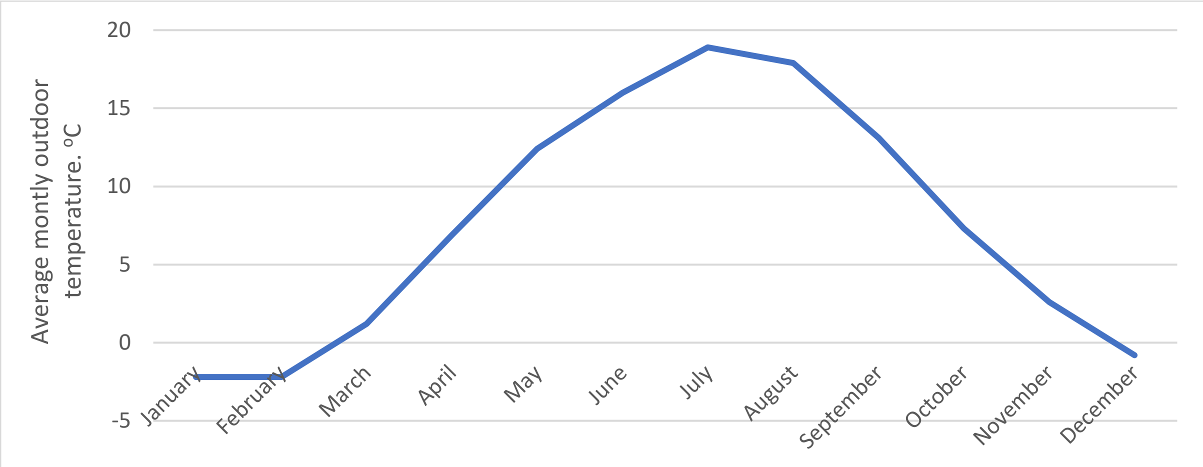


Figure 67. The average monthly outdoor air temperature in Riga

The coldest months typically are January, February and December. According to Latvian National Building code on average there are 192 heating days, with an average outside air temperature of 1.1ºC, which for an indoor air temperature of 20ºC. would equate to 3,630 degree-days. The average outside air temperature for the coldest five days in a year is -9.5ºC, with absolute minimal temperatures reaching approximately -20ºC.

3.2 Population characteristics

Since 1991, Riga, as most areas of Latvia, has seen a gradual decline in the number of inhabitants (i.e., the population has decreased by 32%). This is partly explained by the decrease in birth rates and the resettlement of the population in near proximity to the capital. At the beginning of 2021, the population of Riga city reached 621,120 people.

Riga is characterised by a multinational composition of the population; the city is mostly inhabited by residents of Latvians (47.2% in 2021) and Russians (36% in 2021). In 2020, the largest number of inhabitants is concentrated in the microdistricts of Soviet-era apartment buildings – Purvciems (55,024 inhabitants, 9%), Kengarags (45,783 inhabitants 7%) and Imanta (43,835 inhabitants 7%). The other neighbourhoods are below 4% (See Figure 68).

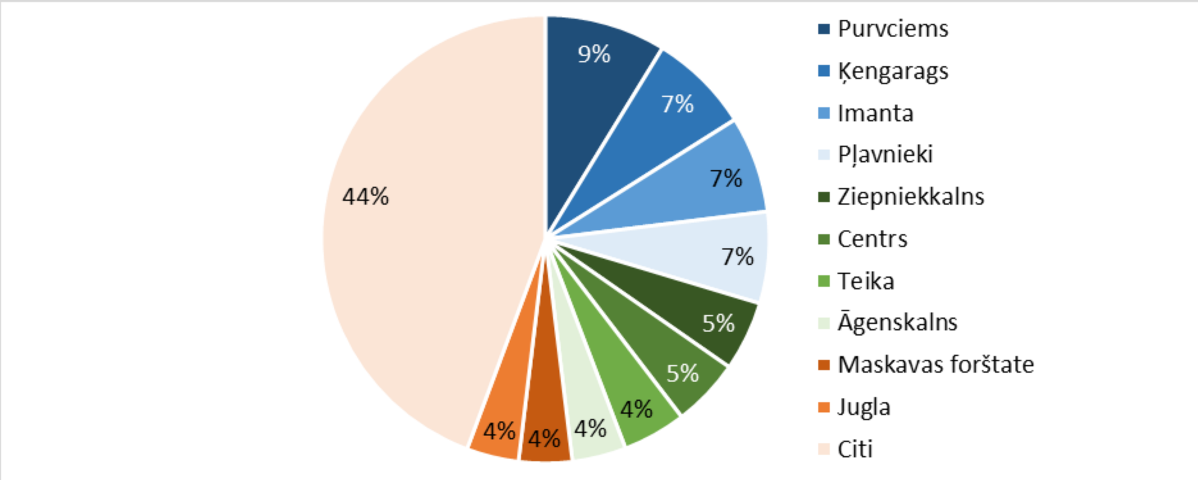


Figure 68. Share of population of Riga neighbourhoods in 2020

Riga's economy forms an important part of the country's economy, it is justified by the volume of GDP, the number of employees, the number of enterprises, investment volumes, as well as other indicators:

- 341,600 or 34.8% of the total economically active population of Latvia live in Riga;
- A total of 480,100 people is employed in Riga, which is 46% of all employed in Latvia;
- 35.1% of all employed in Riga are residents of Riga.

3.3 Housing characteristics

Three or more apartment buildings are considered to be apartment buildings. In the city of Riga in total there are 11.7 thousand such buildings, which is 29.7% of the total number of apartment buildings in Latvia. Referring to the data provided by the REA, the total useful area of apartment buildings in Riga is 18,615 thousand m^2, where the average useful area is 1,585 m^2 per building.

Apartment buildings and their quarters are located in different areas of the city of Riga. Based on the years of construction of apartment buildings, which also affect their energy performance requirements, they can be divided into the following groups:

1. Pre-war buildings built until 1945. They are basically located in the Riga City Centre District and the Old Town.
2. Buildings built during soviet occupation (USSR) built between 1946 and 1991, which are mainly located in the peripheral districts of the city of Riga (e.g., Bolderāja, Imanta, Mežciems, Pļavnieki, Purvciems, Ziepniekkalns, Zolitūde, etc.). They account for the largest share of apartment buildings in Riga both in number and area.
3. New buildings built after 1992, which are located in different districts of the city of Riga and are in relatively small numbers.

The largest share of buildings (59%) are buildings that were put into operation in the period up to 1945. Buildings put into operation in the period from 1946 to 1993 have the largest useful area

(56% of the total), that is, buildings built during the USSR. Examples of the buildings are shown in Figure 69.

Figure 69. Examples of multifamily buildings built in time period from 1946 to 1993

Studies show that the energy efficiency requirements of multi-apartment buildings built during the USSR occupation and up to 2015 do not comply with the requirements of the currently valid Cabinet Regulation No. 280 “Regulations Regarding the Latvian Construction Standard LBN 002-19 "Thermal Engineering of Building Envelopes”. Changes in the regulatory requirements for multi-apartment buildings in relation to specific energy consumption for heating, according to the year of construction of the building, are shown in Table 16. Exceptions in terms of energy performance requirements are specified for buildings that correspond to the status of cultural monuments.

Table 16. Changes in energy efficiency regulatory requirements for multi-apartment buildings

	1980	1992	2003	2015	2016	2017-2018	2019-2020
	Specific heat consumption for heating, kWh/m2 per year						
New buildings	150-200	100-130	70-90	60-85	≤70	≤60	≤50
Refurbishment and redevelopment	-	-	-	≤90			

Riga has a high share of buildings in need of deep renovation (about 6,000 apartment buildings) and at the same time low activity of renovation of existing buildings. By 2019, only 159 or 1.4% of the total number of apartment buildings in the city of Riga have been renovated in Riga.

Building managers play an important role in promoting the renovation of multi-apartment buildings. Riga has a lot of competition in the house management market, as well as many new companies that are entering. One of the largest management companies is SIA "Rīgas namu managers" (RNP), which manages 4284 residential buildings. In total, more than 170 building management companies and more than 500 apartment owners’ cooperative societies (DzĪKS) are registered in the city of Riga.

3.4 Energy poverty and vulnerability

The analysis in Riga pilot about the energy poverty rates was based solely on data from Eurostat's EU SILC survey, which were downloaded by the Portal of the Official Statistics of Latvia. The EU SILC survey microdata (at household level) were available for the years 2017-2021. From the dataset, the observations selected were those that referred to Riga region (variable reg) and urban territory (variable laupil).

According to Figure 70, the share of population living in a dwelling with a leaking roof, damp walls/floors/foundation within the Latvian pilot area is lower than the national share by nearly 3.5-6%. Similarly, the share of population with arrears on utility bills is lower in the pilot area than at country level (Figure 72), with the difference decreasing over time, from 2.5% in 2017 to 1% in 2021. Conversely, the share of population not being able to keep home adequately warm is higher in the pilot area compared to the national average (Figure 71), with the discrepancy gradually decreasing from 6.8% in 2017 to 2.5% in 2021.

In general, it appears that the consensual EP indicators are improving so much in the pilot area as nationally, while also the discrepancy between the two levels is significantly smaller over the years.

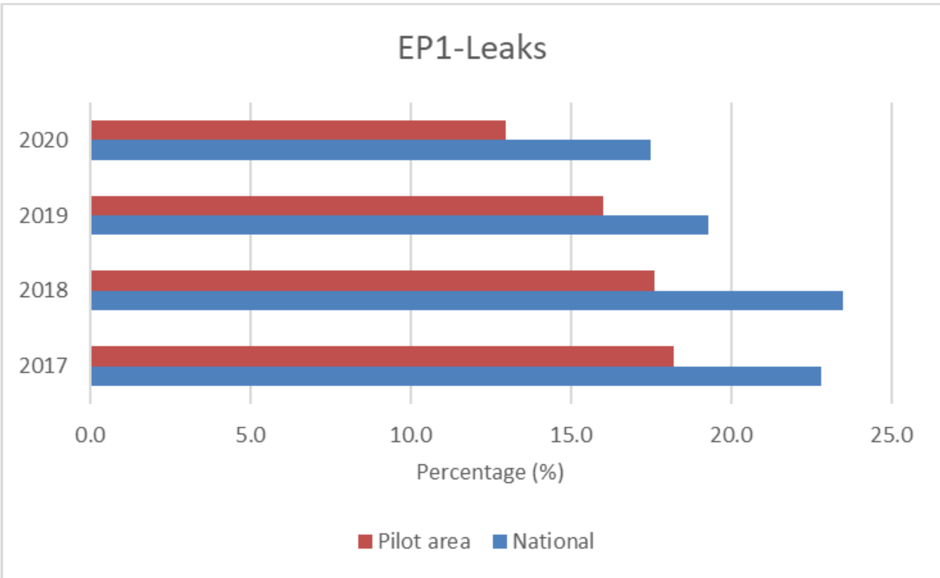


Figure 70. Share of total population living in a dwelling with leaks

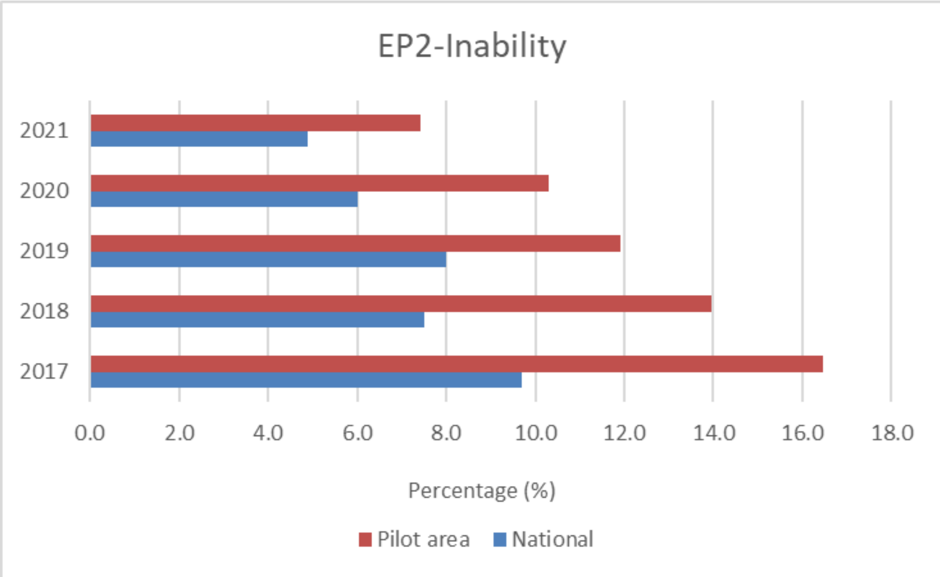


Figure 71. Share of population not able to keep home adequately warm

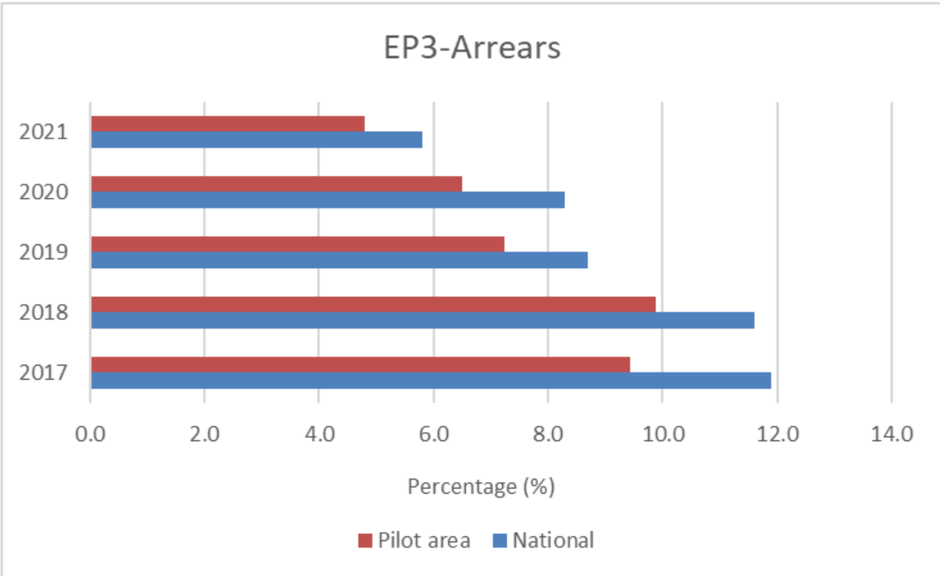


Figure 72. Share of population having arrears on utility bills

EP4 to EP12 were only examined at the pilot area level, as not being official indicators. Figure 73 reveals that the share of population that has fallen behind on its utility bills only once decreased from 3.5% in 2018 to 0.9% in 2021. Figure 74 shows that the percentage of the population that has had arrears on their utility bills two or more times is significantly higher than the case of falling behind only once and, in fact, it decreased from 7% in 2017 to 3.9% in 2021.

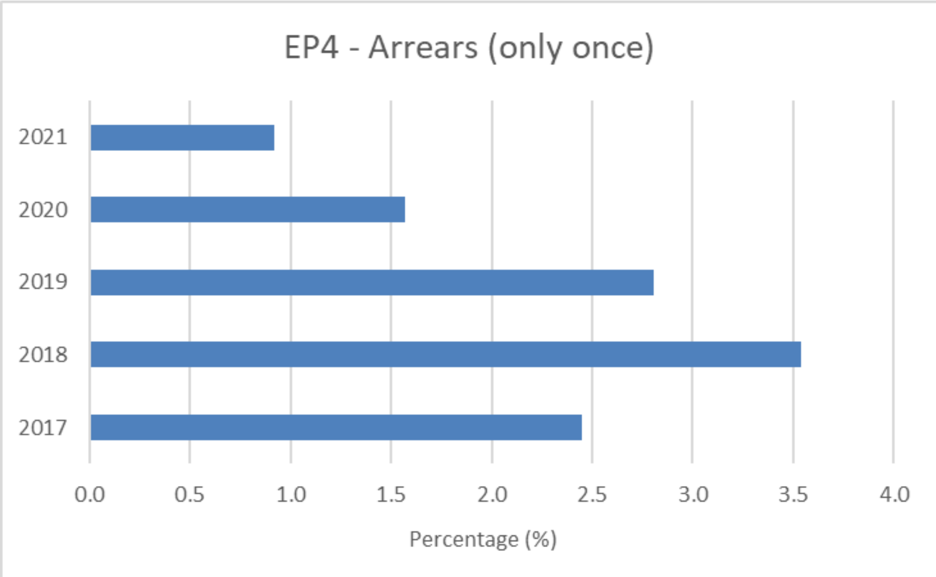


Figure 73. Share of population having arrears on utility bills only once in the past 12 months

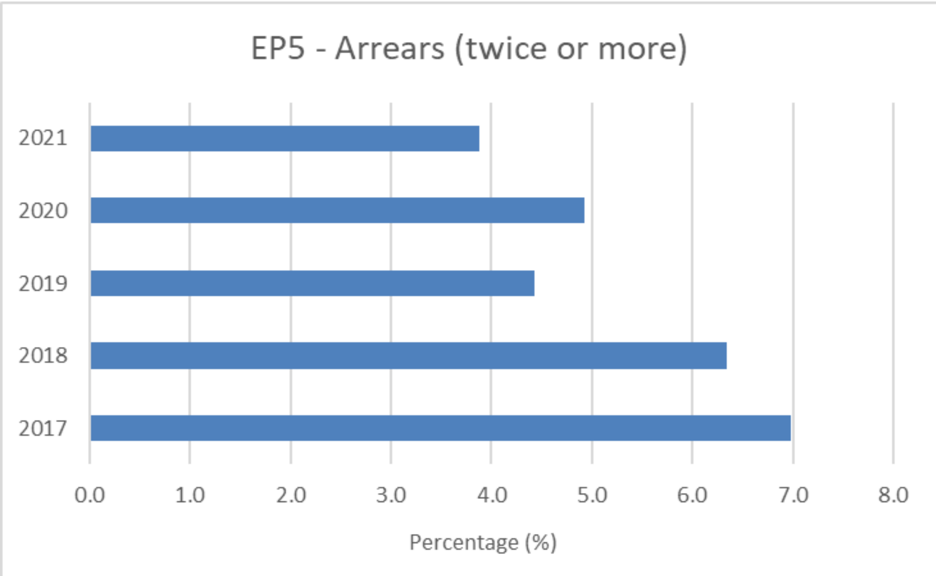


Figure 74. Share of population having arrears on utility bills twice or more in the past 12 months

The results of the Weighted Composite Indices (WCI1, WCI2, WCI3) reflect the better condition of the energy poverty problem over the years. Indicatively, as regards the WCI1 (Figure 75), the share of population not experiencing EP issues increased from 65.8% in 2017, to 76.7% in 2020, while the share of population experiencing severe EP issues (i.e., WCI1 equals to 1) decreased from 1.2% in 2017 to 0.6% in 2020. Similar results derive from Figure 76 and Figure 77, regarding WCI2 and WCI3, respectively.

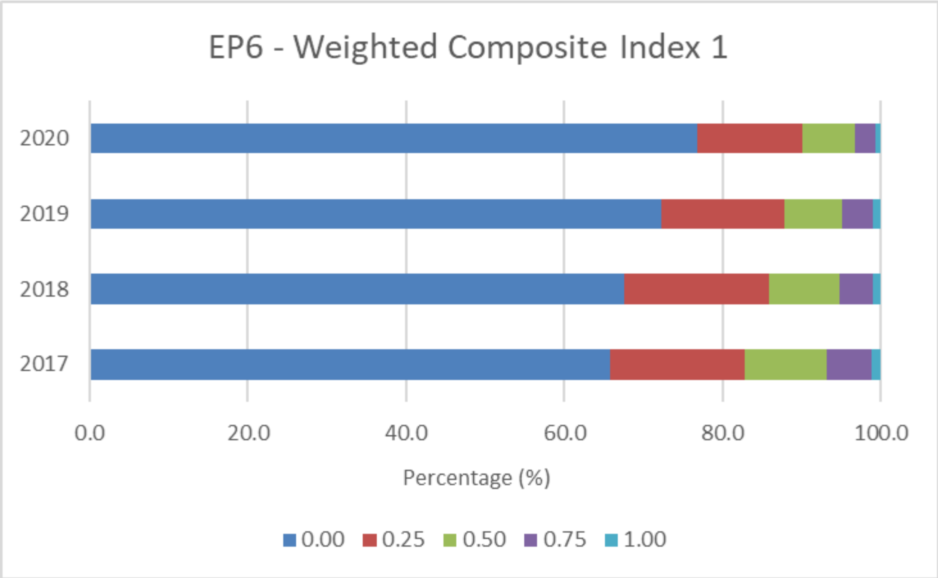


Figure 75. Share of population at EP according to WCI1

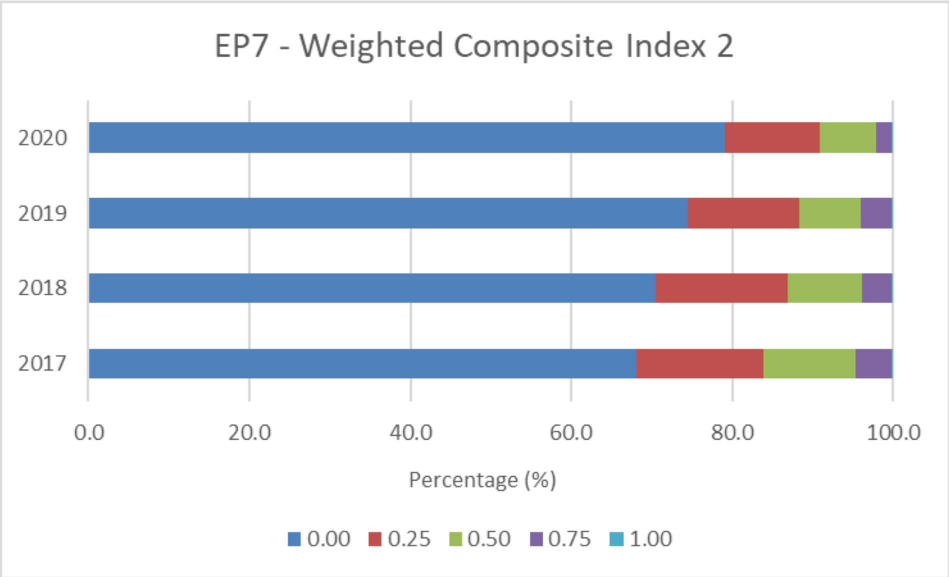


Figure 76. Share of population at EP according to WCI2

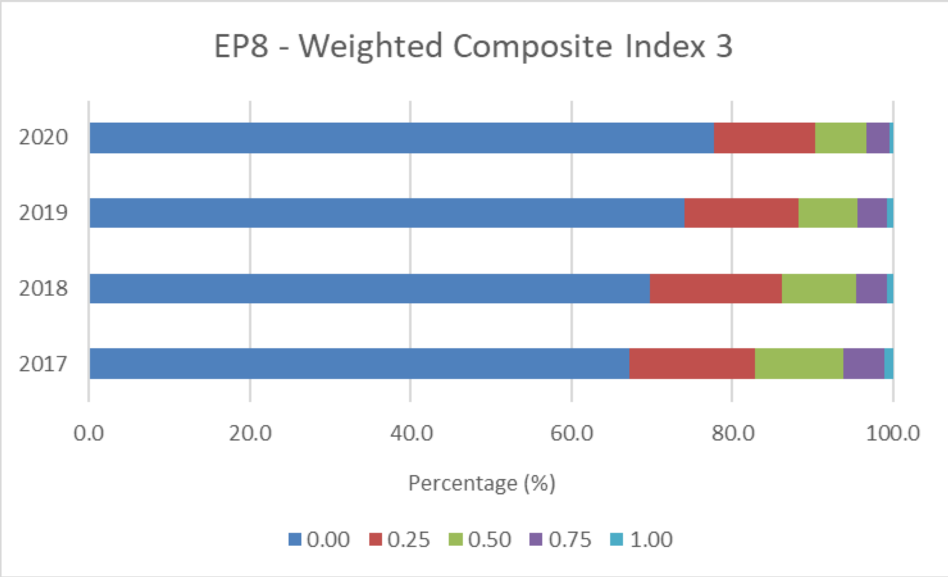


Figure 77. Share of population at EP according to WCI3

The Simple Composite Indices (SCI1, SCI2 and SCI3) also reveal a better condition of the energy poverty problem over the years. As shown in Figure 78, Figure 79 and Figure 80, the share of population not experiencing EP issues increased from 2017 to 2020 for all the 3 SCIs, while that experiencing severe EP problems (classes 2 and 3) decreased. Indicatively, as regards the SCI1 (Figure 78), the EP rate for class 2 decreased from 7% to 3.8% between 2017 and 2020 (a percentage reduction of 45.7%) and for class 3 from 1.2% to only 0.6% (a percentage reduction of 50%).

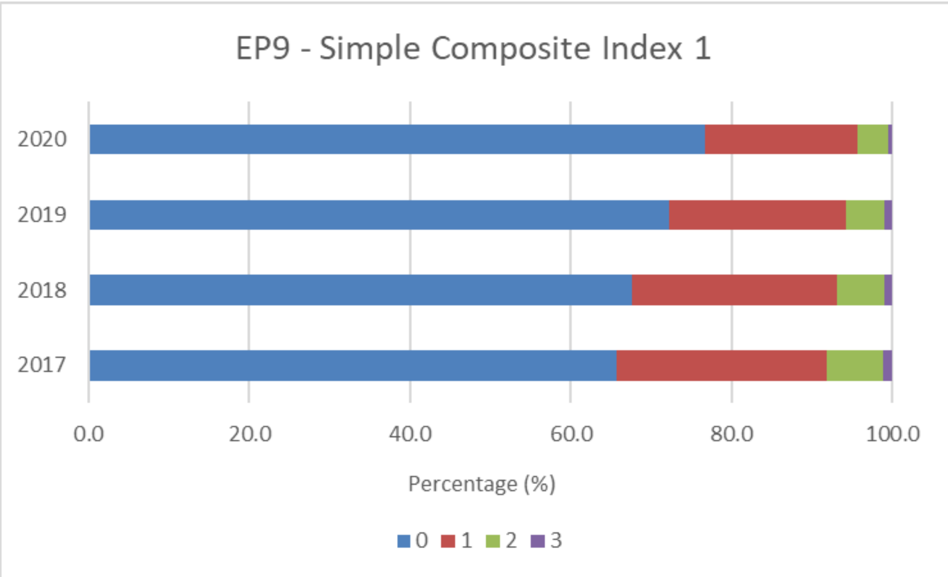


Figure 78. Share of population at EP according to SCI1

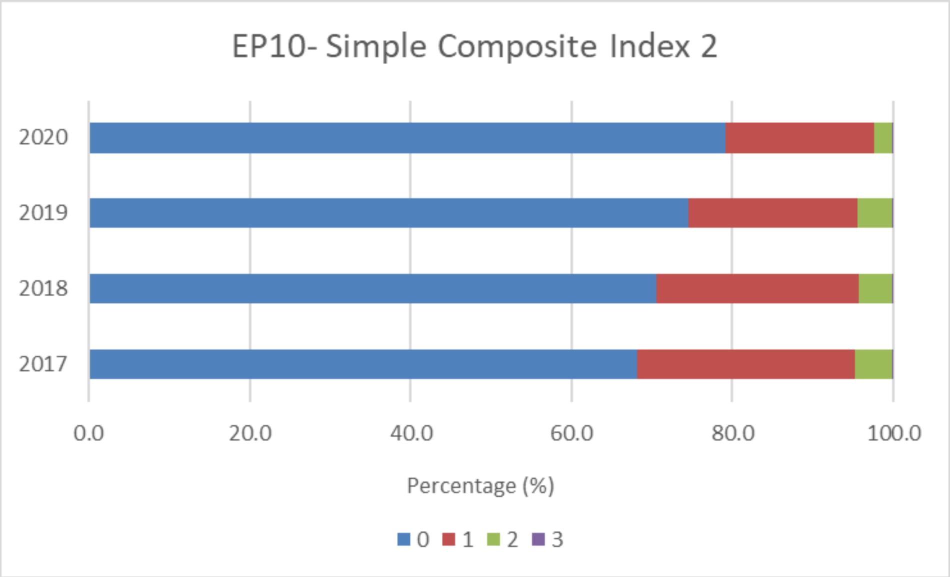


Figure 79. Share of population at EP according to SCI2

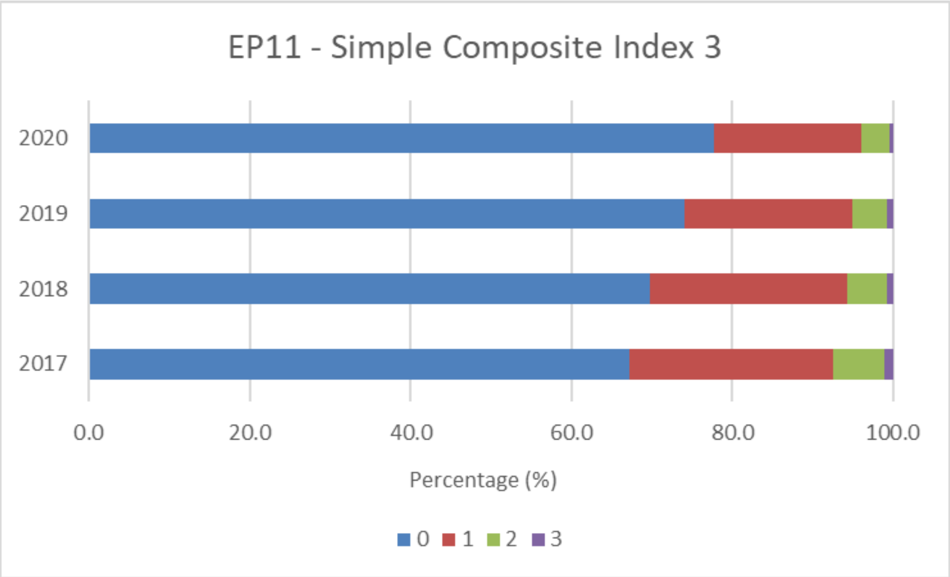


Figure 80. Share of population at EP according to SCI3

Finally, as shown in Figure 81, the share of population experiencing any type of EP within the pilot area, i.e., inability to keep home warm, arrears on utility bills or leaks, damp walls/floors/foundation is steadily decreasing over time. This indicator shows high percentages as, practically, all individual EP indicators are taken into consideration.

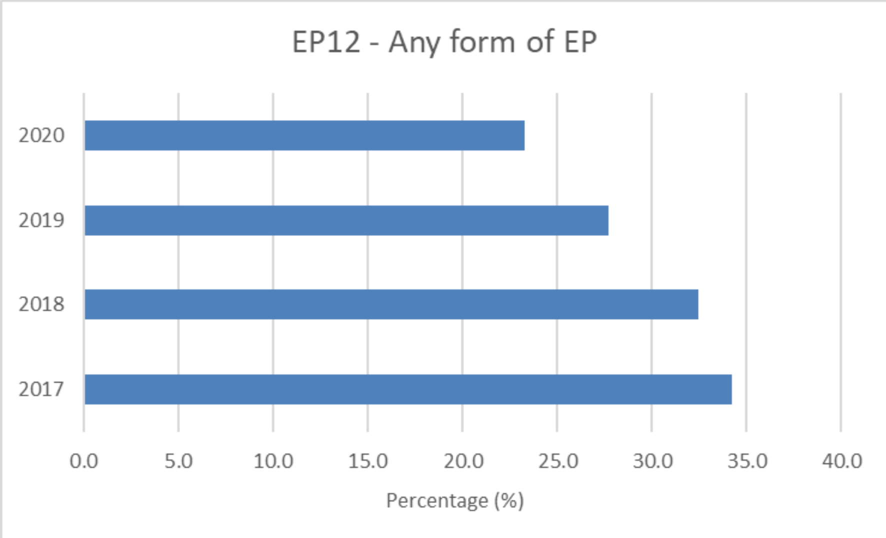


Figure 81. Share of population at EP according to EP12

Below, certain housing characteristics and living conditions of households are examined in relation to the above investigated indicators, to explore the effect of these characteristics on EP vulnerability in the pilot area.

As shown in Figure 82, households living in large buildings do not experience EP problems (leaks, inability to keep home adequately warm, arrears on utility bills), apparently, due to their higher incomes on average. On the contrary, households living in semi-detached or terraced houses and those living in small buildings face higher problems with leaks, with those living in small buildings facing also the highest difficulty in keeping their apartments adequately warm. Finally, households living in detached houses are the ones that face higher problems with arrears on utility bills.

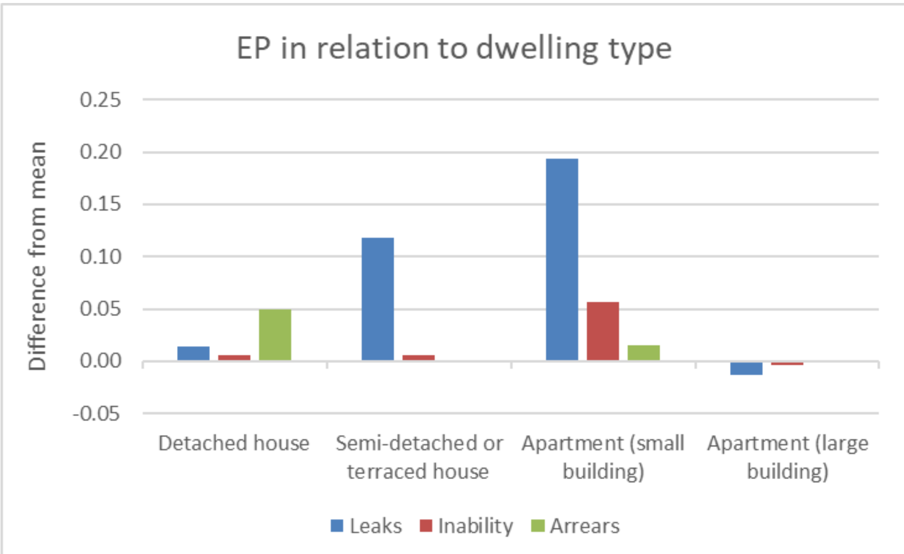


Figure 82. Leaks, inability to keep house warm and arrears on utility bills in relation to dwelling type

The dwelling size is also related to the three basic EP indicators (leaks, inability to keep home adequately warm, arrears on utility bills). As shown in Figure 83, households living in houses with one room present the highest EP rates compared to the average rate, followed by those living in 2-rooms houses. On the contrary, households living in larger houses (3, 4, 5 or more rooms) present lower EP rates compared to the average, probably due to the higher incomes of these households. It should be noted, though, that households living in large houses (5 or more rooms) seem to face problems with arrears on their utility bills.

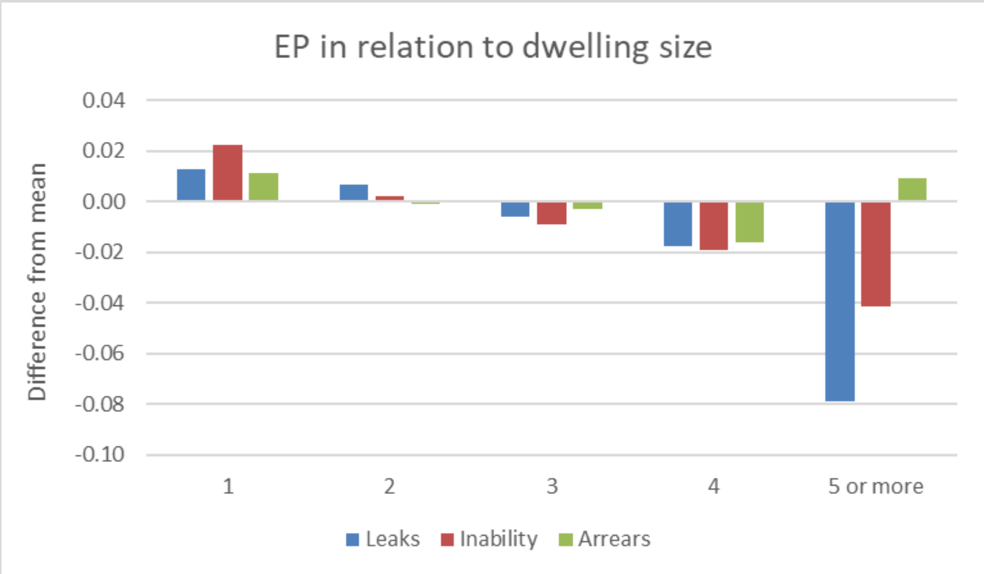


Figure 83. Leaks, inability to keep house warm and arrears on utility bills in relation to dwelling size

As regards tenure status, tenants who pay rent at reduced rate seem to be more prone to energy poverty, followed by tenants who pay rent at market rate (Figure 84). It is also noteworthy that among all groups, those living at free accommodation status are the most vulnerable ones in terms of keeping their home adequately warm. On the other hand, owners seem to face less EP problems with respect to the average rate.

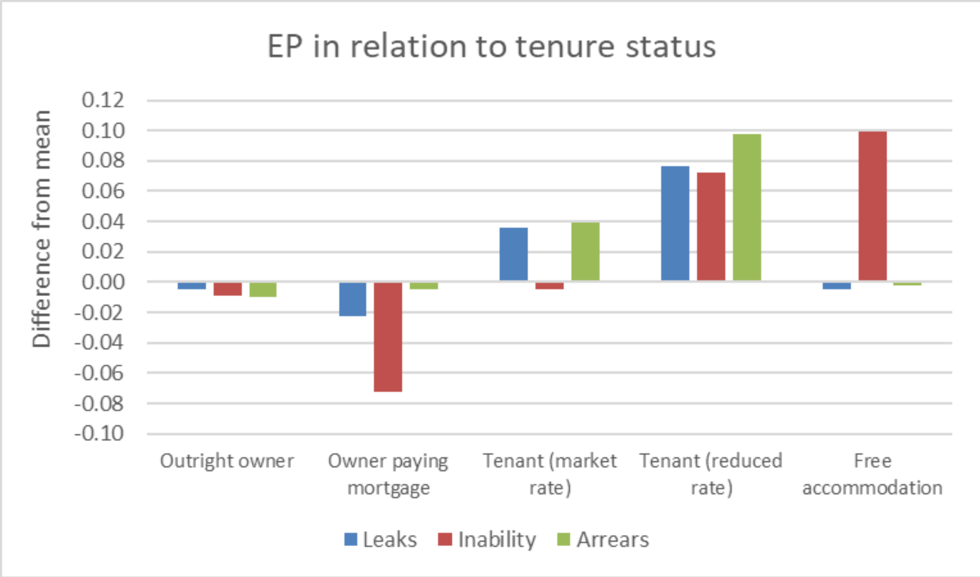


Figure 84. Leaks, inability to keep house warm and arrears on utility bills in relation to tenure status

The level of difficulty in terms of making ends meet is related to the three EP indicators examined. Specifically, Figure 85 shows that households experiencing great difficulty in making ends meet present higher EP rates of up to 20% versus average rates. On the contrary, households that can easily (fairly easily up to very easily) make ends meet present quite lower EP rates (up to 12%) compared to average rates.

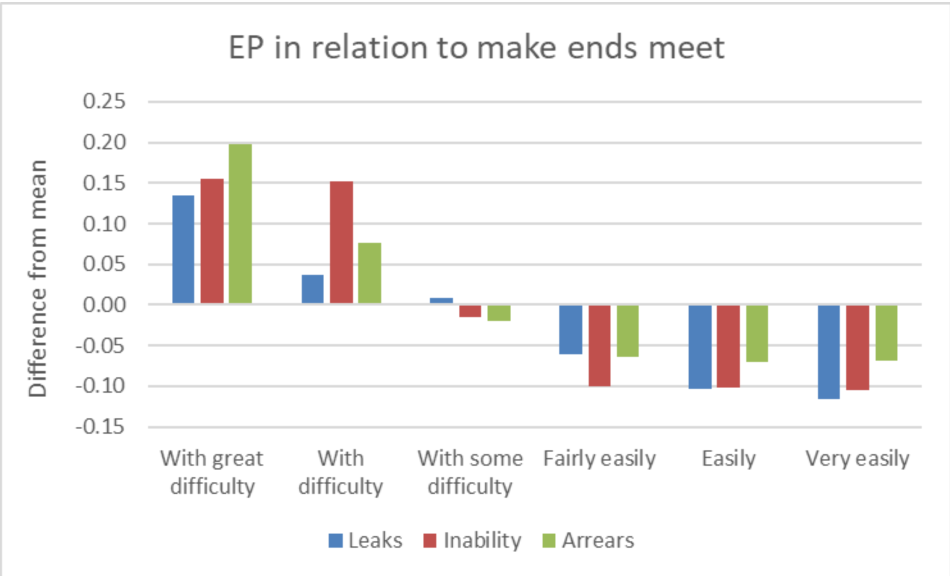


Figure 85. Leaks, inability to keep house warm and arrears on utility bills in relation to the level of difficulty in making ends meet

Similar trends are observed in the case of complementary EP indicators. Indicatively, households living in small buildings, followed by those living in semi-detached or terraced houses (Figure 86), households living in a one- room home (Figure 87), tenants that pay rent at reduced rate (Figure 88) and households experiencing difficulty to make ends meet (Figure 89) present higher rates of all EP indicators compared to the respective average rates.

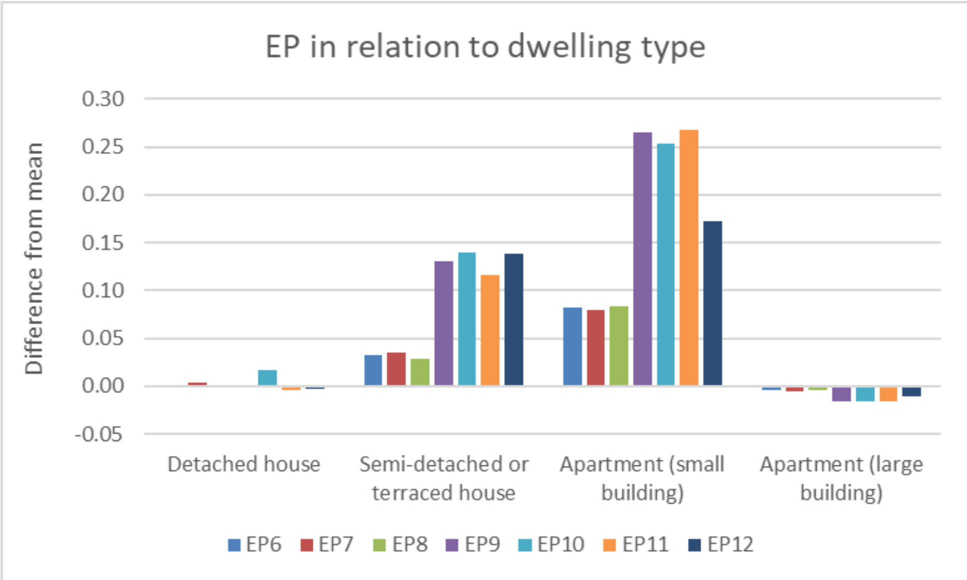


Figure 86. Complementary EP indicators in relation to dwelling type

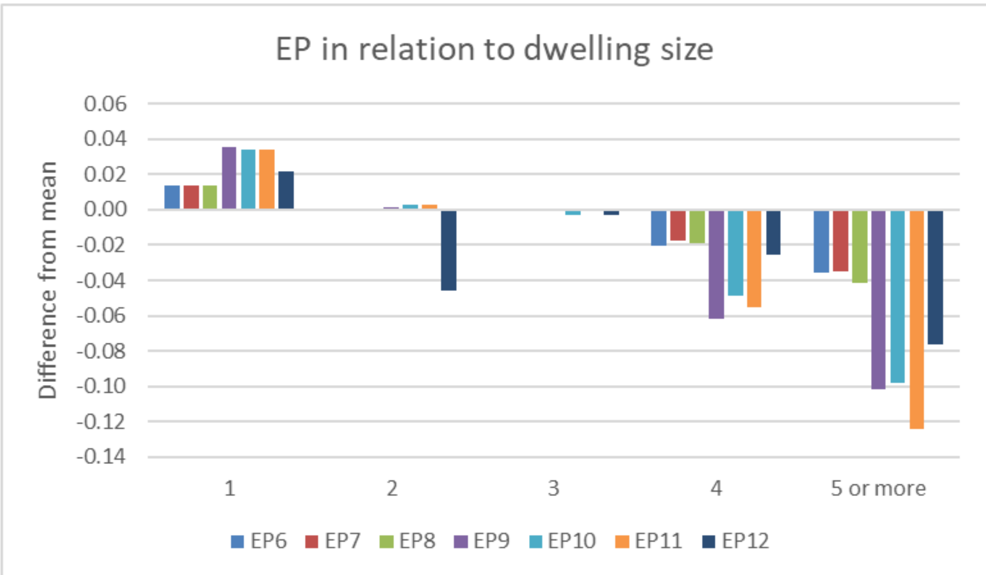


Figure 87. Complementary EP indicators in relation to dwelling size

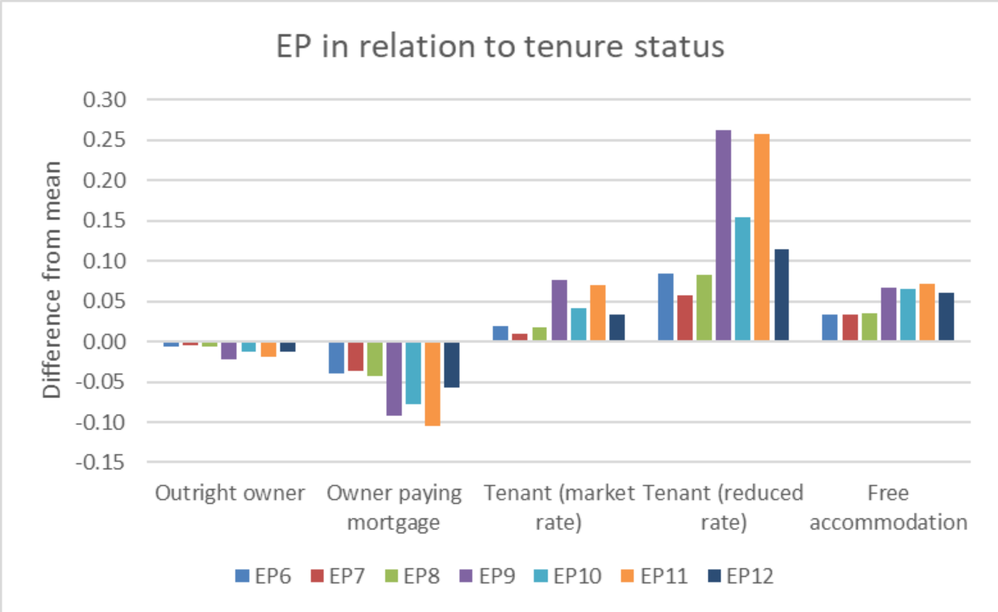


Figure 88. Complementary EP indicators in relation to tenure status

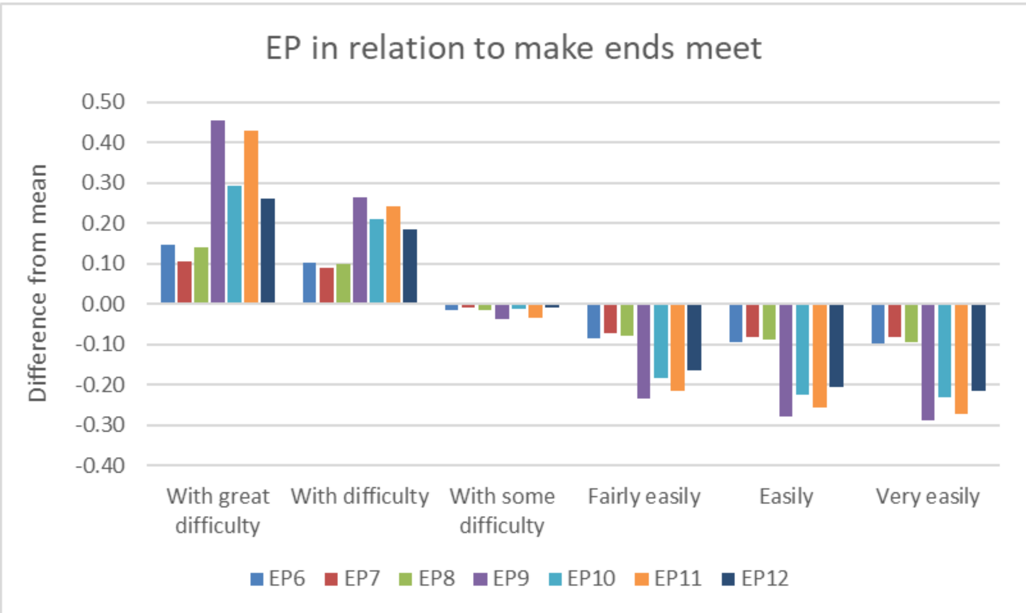


Figure 89. Complementary EP indicators in relation to the level of difficulty in making ends meet

4 Pilot 4 - Coimbra (Portugal)

4.1.1 Area characteristics

The Intermunicipal Community of Coimbra Region is an administrative division in Portugal. It was created in October 2013, replacing the previously existing Greater Metropolitan Area of Coimbra. Since January 2015, Coimbra Region is also a NUTS3 subregion of Centro Region, which covers the same area as the intermunicipal community. The main city and seat of the intermunicipal community is Coimbra. The metropolitan area of Coimbra has a population of around 435 000 inhabitants, distributed over an area of 4 335,57km². Figure 90 presents the geographical location of the selected Pilot Region.

NUTS II

NUTS III

The Coimbra Region is a statistical sub-region of level III (NUTS III), part of the Centre Region.

Figure 90. Geographical location of the selected Pilot

Located at an elevation of 40.19 meters above sea level, Coimbra, like most of Portugal, has a warm Mediterranean climate according to the Köppen climate classification: Hot-summer Mediterranean climate (CSa) and Warm-summer Mediterranean climate (CSb).

The city’s yearly temperature is 16.78ºC and it is -0.03% lower than Portugal’s averages. Coimbra typically receives about 92.11 millimeters of precipitation and has 105.45 rainy days (28.89% of the time) annually. The main geographical and weather data is the following:

- Longitude - 8.4102573
- Latitude - 40.2033145
- Attitude/Elevation - 40.19m
- Average annual high temperature - 20.99ºC
- Average annual low temperature - 9.97ºC
- Average annual precipitation - 92.11mm
- Warmest month - August (average temperature 29.64ºC)
- Coldest Month - January (average temperature 5.39ºC)

- Wettest Month - January (143.37mm)
- Driest Month - July (8.44mm)
- Average days of heating per year: Heating Degree Days in Coimbra Region – 1136,5 (2022)[1]
- Average days of cooling per year: Cooling Degree Days in Coimbra Region: 114,4 (2022)

4.1.2 Population characteristics

The Coimbra Municipality, located in the Portugal Centre Region, has around 135,000 inhabitants. Its population is considerably aged (Figure 91), with an ageing index of 203.9 against the Portuguese average of 157.4 and the EU27 average of 132.3. In 2018, the Gini Coefficient in the region was 4.7.

Being mostly a city of the Services sector, with the main activities being related to health sector services, including hospitals, schools, and Universities, the Coimbra population, on average, has a good level of education and reasonable purchase power, when compared to other cities or rural areas. Nevertheless, when focusing on the neighbouring areas, and on the elderly living in social houses and in the downtown, where the housing stock is very old and inefficient, energy poverty in Coimbra is a major social issue.

The pilot will be focused on the most vulnerable households of the Municipality of Coimbra, who live in social houses under the management of the Municipality, in a very open and quiet suburban area, not far from the city centre. The target audience of REVERTER Pilot includes a population of about 150 citizens, who live in the poorest neighbourhood of the city; inhabitants facing the higher risk of poverty, mainly single parents, especially women, unemployed, ethnic minorities, and families with more than 3 children.

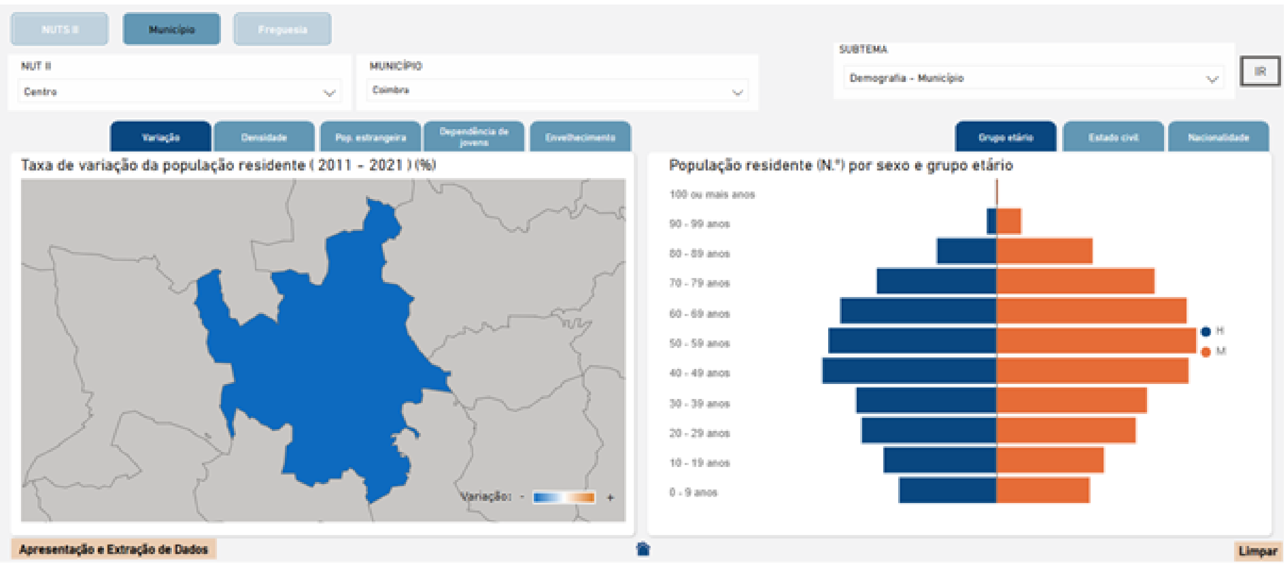


Figure 91. Distribution of the population by age

[1] https://ec.europa.eu/eurostat/databrowser/view/NRG_CHDDR2_A__custom_5432047/default/table?lang=en

4.1.3 Housing characteristics

Residential buildings represent the vast majority of the building stock in Portugal, with 77% of the buildings (Monzón-Chavarrías et al., 2021). Most of the buildings were built before 1980 (53.5%), i.e., before the first thermal building code was enacted in 1990. Therefore, these buildings do not have any thermal insulation. The decades 1961–1980 are typically considered as a period with buildings with a poor energy performance. For example, some experts studied the constructive solutions and energy performance of Portuguese buildings and argue that buildings erected during the 60’s, 70’s and 80’s are the ones with the highest energy saving potential (Sousa et al., 2013). Other experts studied the energy performance certificates of residential buildings in Portugal and found that buildings erected before 1980 have higher levels of nominal heating energy needs (Magalhães & Leal, 2014). Additionally, the performance of the buildings in the inner part of the centre region is lower than in the more coastal area.

The building characteristics of Coimbra region are influenced by its historical and cultural heritage, as well as its geographical and climatic conditions. Coimbra has a variety of architectural styles, ranging from Romanesque, Gothic, Renaissance, Baroque, to Modernist. The traditional buildings in Coimbra are mostly made of stone, brick, and timber, with tiled roofs and plastered walls. In the old city, the buildings are usually arranged along narrow streets and alleys, forming dense urban blocks and are, in general, in bad condition. Some of the common building features are balconies, arcades, courtyards, and decorative elements such as azulejos (painted ceramic tiles), stucco, and wrought iron. The city has grown in the decades 60´s-90´s with a boom of new constructions, mainly buildings with more than 4 floors and new districts have been set in the city.

The quality of residential buildings in the Coimbra region is affected by several factors, such as the design, materials, construction, maintenance, and performance of the buildings. The quality can be measured by different criteria, such as structural safety, durability, functionality, comfort, aesthetics, energy efficiency, and environmental impact. According to a previous study, the majority of the traditional buildings in Coimbra have a high seismic vulnerability due to their poor structural condition and lack of adequate seismic capacity (Vicente et al., 2006). The study also found that the main causes of defects in the construction stage of residential buildings are related to the construction materials, inspections, equipment, management, and human errors. Therefore, it is recommended to adopt proper quality management practices and standards for the design, construction and rehabilitation of residential buildings in Coimbra region.

The decades with the highest percentage of buildings constructed in Portugal were 1961–1980 (~30%) and 1981-1990 (~16%) [6]. The period 1961–1980 is included among the decades with the highest building construction growth. Additionally, this is considered the period where buildings had poorer energy performance. For these reasons, the REVERTER residential reference building in the national building stock, our baseline, was chosen to represent the characteristics of the social housing buildings of this period, in the centre region. Most of the multi-family buildings built between 1971 and 1980 in Portugal have 2 floors (33.7%) or 3 floors (19.4%), and the dwellings have a useful floor area of 70–99 m2 (19.9%). Windows occupy 17–23% of the façades (Monzón-Chavarrías et al., 2021). The Pilot has 4 floors and 65 m^2 of useful floor area per dwelling.

Regarding the type of construction, the majority of the Portuguese multi-family buildings built between 1971 and 1980 have reinforced concrete structures (54.15%), rendered and painted façades (88%), and pitched roofs with ceramic tiles (93.4%)[2]. The construction data of the Portuguese buildings are obtained from an official report on the thermal performance of buildings and the application of the Portuguese building thermal regulation [LNEC] and contrasted with other sources (Brandão de Vasconcelos et al., 2015; Palma et al., 2019). According to National Statistics in Portugal[3], electricity is the main energy source for heating, followed by gas, LPG (butane) and wood biomass. The main energy source for heating DHW is gas, followed by LPG (butane). Space cooling is provided solely by electricity.

Since the identification of the cost-optimal levels of minimum energy performance requirements cannot be calculated for every individual building, the EPBD requires all MSs to characterize first the building stock and then establish the Reference Buildings (RBs) that represent the stock. To characterize the reference building, the choice was to select a real building representing the most typical building in a specific category (building function type) for the Centre region (building location) and built before the Thermal building Code (construction period) (Brandão de Vasconcelos et al., 2015). This methodology of selecting a building that already exists requires a large amount of well-characterized information about the building, as well as of the building stock, but does not require supplementary information (like statistical analysis, etc.) (Brandão de Vasconcelos et al., 2015). Since the Coimbra Pilot focuses on Social Housing owned by the Municipality, the risk of having characteristics that are not representative of buildings in the same sample is very low.

The Coimbra Pilot will focus on developing 2 roadmaps (for buildings and houses) targeted to consumers who are particularly vulnerable concerning thermal comfort levels in their homes. Solutions will not focus only on the building envelope and energy-efficient appliances but also on the urgent need to switch fossil fuel-based heating and cooking systems using gas to electricity by promoting solar thermal and photovoltaics, as well as its integration in REC. Although with limitations regarding indicators and hard data, it is well known that the region has an at-risk-of-poverty rate of 17.3%. At-risk or EP vulnerable households have been signalled by the Municipality services working in the field. However, due to the shortage of public budgets and other priorities (e.g., investing in public infrastructures or services, security, etc., which are more visible to citizens), programs dedicated to building renovations are scarce and actions to tackle EP have been limited. The Coimbra Pilot will be focused on the most vulnerable households of the Municipality of Coimbra, who live in social houses under the management of the Municipality.

The Coimbra Municipal Housing Park (social housing) consists of a total of 854 dwellings, with different typologies, integrating building apartments and houses dispersed over the city. The buildings were built before the first building code entered into force in 1990, and therefore those buildings do not have any thermal insulation. Part of the social housing park in the city centre has recently undergone some retrofits, but the actions taken were mainly on painting the façades. Hence, the existing potential for energy renovations is high. Moreover, a large share of inhabitants is elderly and low educated, who cannot afford to carry out improvements and construction works or do not have the knowledge on how to start the renovation journey, and therefore a holistic

[2] https://www.eppedia.eu/article/energy-efficiency-housing-stock-portugal

[3] https://censos.ine.pt/xportal/xmain?xpgid=censos21_habitacao&xpid=CENSOS21

approach is required to have a high impact. Sound impartial advice on what is best for improving the overall environment and actions geared towards behavioural changes and capacity building can lead to significant improvements in households' well-being.

4.1.4 Energy poverty and vulnerability

The analysis of the current situation of energy poverty and vulnerability of the population in the pilot of Coimbra was based only on data from Eurostat's EU SILC survey. The Statistics Portugal provided EU SILC survey microdata (at household level) for the years 2017-2021. Nevertheless, for 2017 there was no separation into NUTS2 regions. For this reason, the final dataset included observations for the years 2018-2021. From this dataset, the observations selected were those that referred to region PT16 (variable DB040) and degree of urbanization 2 (variable DB100 - towns and suburbs/intermediate area). This subset of the data includes other areas than Coimbra, but with similar characteristics.

According to Figure 92, the percentage of population living in a dwelling with leaks, damp or rot in the Portuguese pilot area is higher than the national average (almost by 2%). It worths noting that leakages-damp problems within the pilot area deteriorated in 2020, marking an increase of up to 23.6%, while also exceeding national rates for the first time.

The percentage of population not being able to keep home adequately warm also exceeds the national percentage (almost by 3%) in the pilot area, with the difference between the two rates increasing in 2021 as compared to the last two years (Figure 93).

A better condition is observed in the case of EP3 indicator (Figure 94), as fewer households seem to have arrears on their energy bills in the pilot area compared to the national level, in 2021. Still, the picture is worse compared the previous three years, as all rates (both at pilot-area level and national level) were significantly lower.

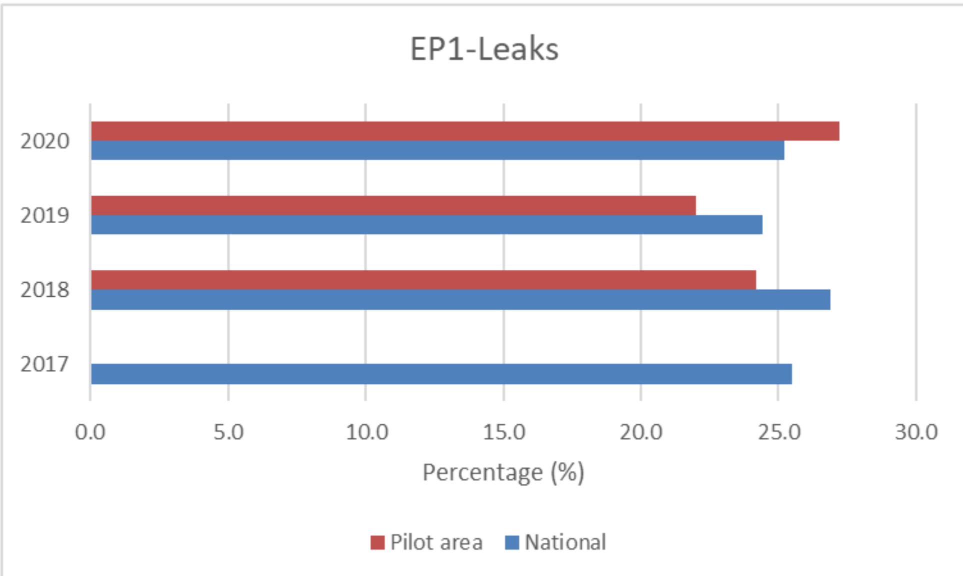


Figure 92. Share of total population living in a dwelling with leaks

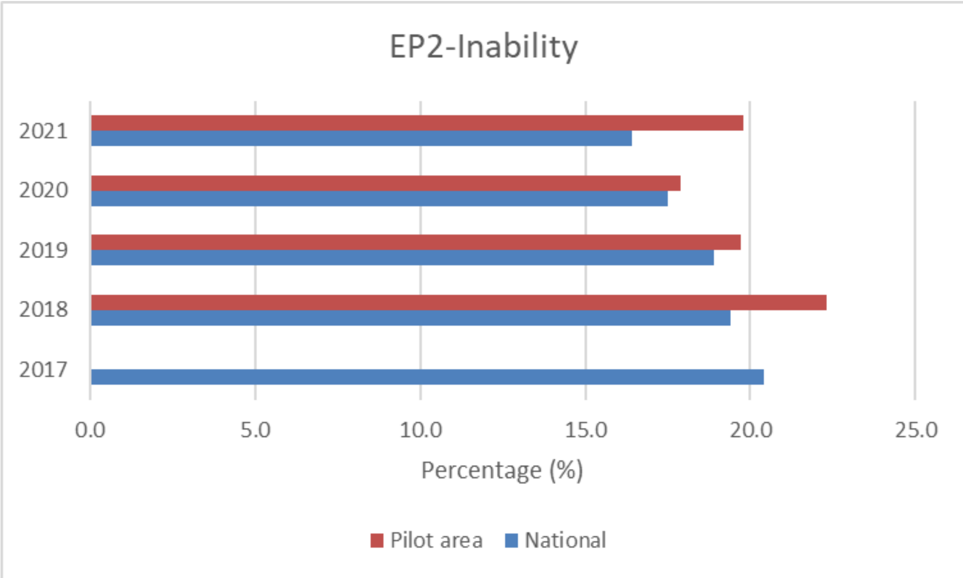


Figure 93. Share of population not able to keep home adequately warm

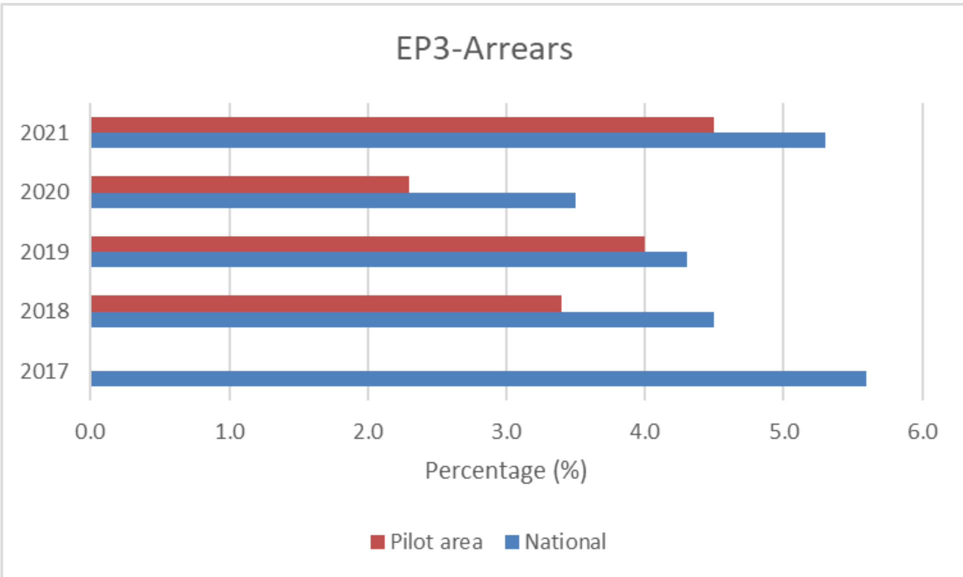


Figure 94. Share of population having arrears on utility bills

As in the other pilot areas, indicators EP4 to EP12 were examined only at level of the pilot area. Indicatively, the percentage of population having arrears on utility bills only once is low, i.e., 1% in 2021 and even lower the previous years (0.1% up to 0.8%) (Figure 95). The corresponding percentage of households with arrears on utility bills twice or more is greater, i.e., 3.5% in 2021 and without significant fluctuations over the years (on the order of 2-3%) (Figure 96).

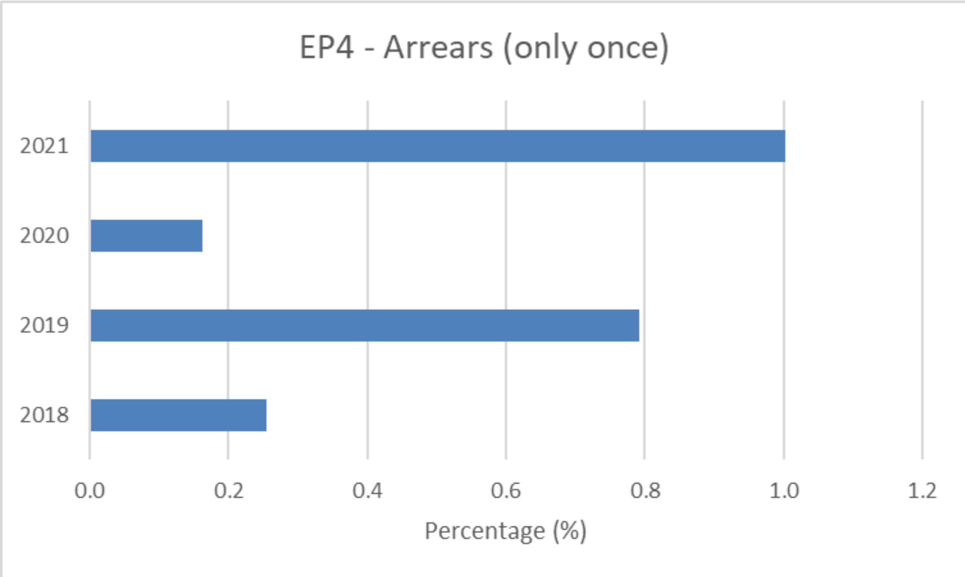


Figure 95. Share of population having arrears on utility bills only once in the past 12 months

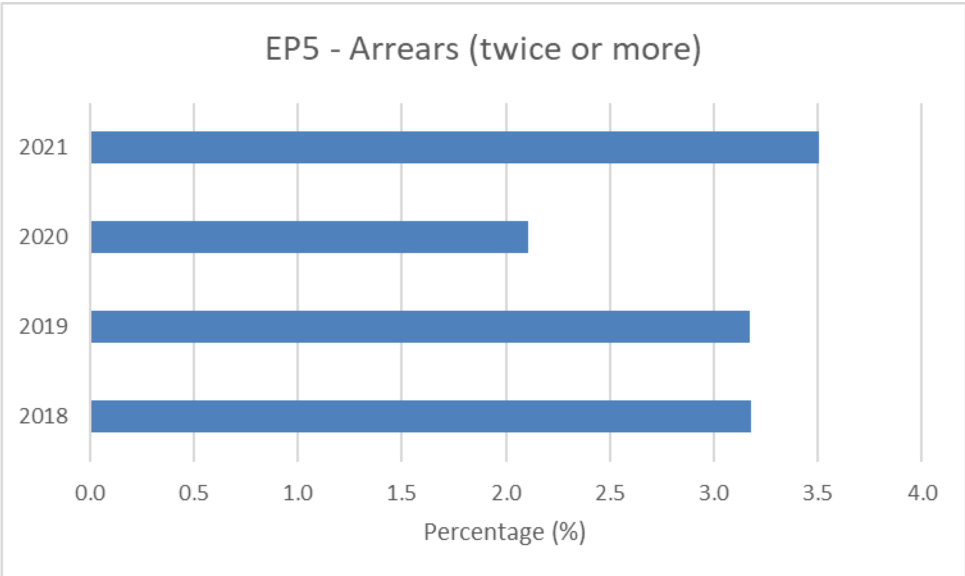


Figure 96. Share of population having arrears on utility bills twice or more in the past 12 months

Figure 97, Figure 98 and Figure 99 illustrate the results of the Weighted Composite Indices (WCI). The energy poverty problem seems to be rather stable over the years according to the three indices. For example, the percentage of the population without EP issues has remained on the order of 60% since 2018, while that with severe EP issues (i.e., WCI1 is equal to 1) has been reduced by 0.3 percentage points since 2018 (Figure 97). Similar conclusions are reached for WCI2 and WCI3, as shown in Figure 98 and Figure 99, respectively.

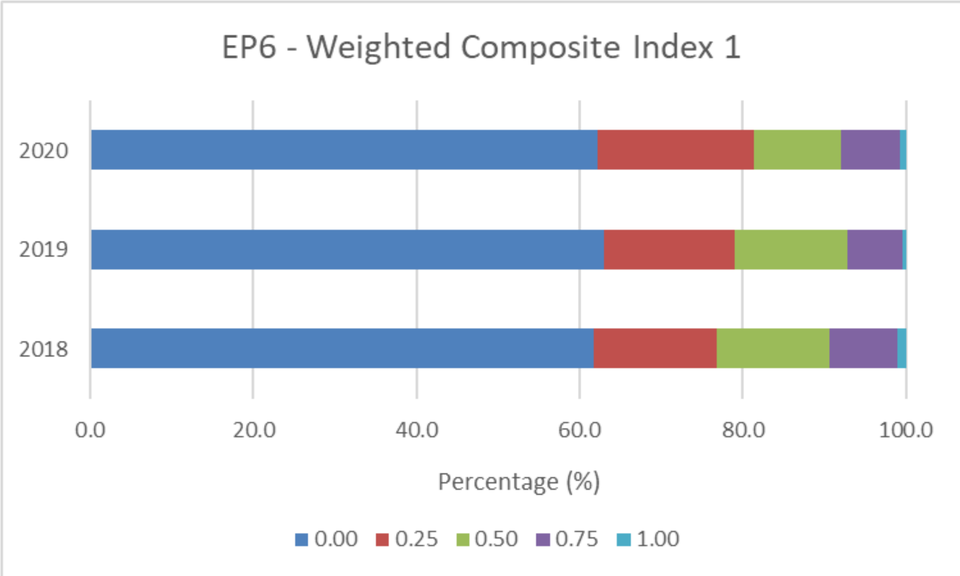


Figure 97. Share of population at EP according to WCI1

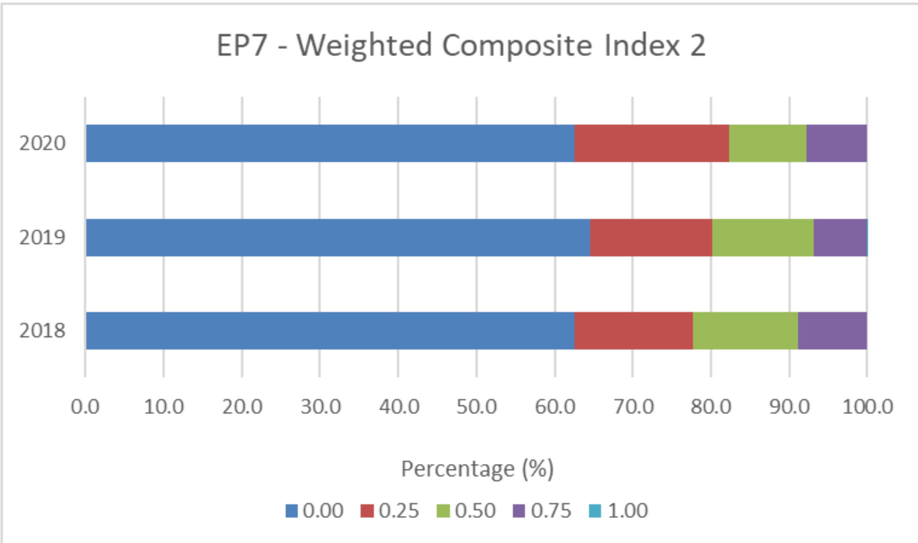


Figure 98. Share of population at EP according to WCI2

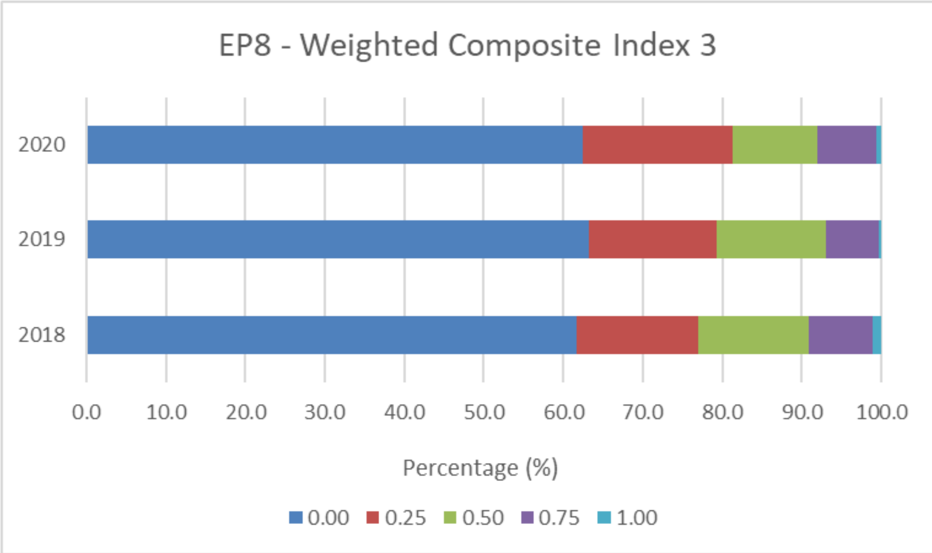


Figure 99. Share of population at EP according to WCI3

The Simple Composite Indices (SCI) also reflect the rather stable condition of the energy poverty problem. In all SCIs, the classes have retained similar rates since 2018. For example, the EP rate for households not experiencing EP issues (class 0) has remained on the order of 60% and the corresponding rate for those experiencing the most important EP problems (classes 2 and 3) has remained on the order of 10% since 2018 (Figure 100, Figure 101 and Figure 102).

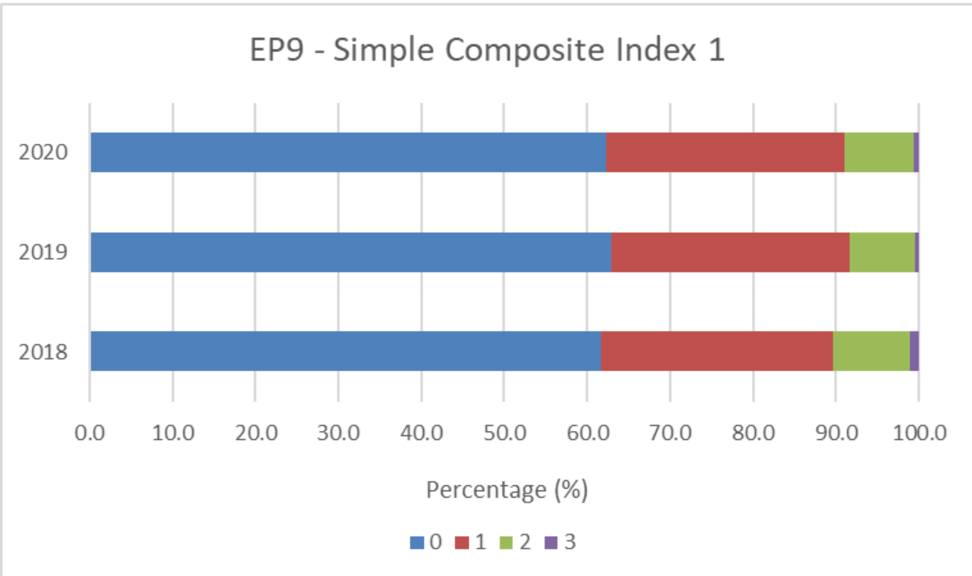


Figure 100. Share of population at EP according to SCI1

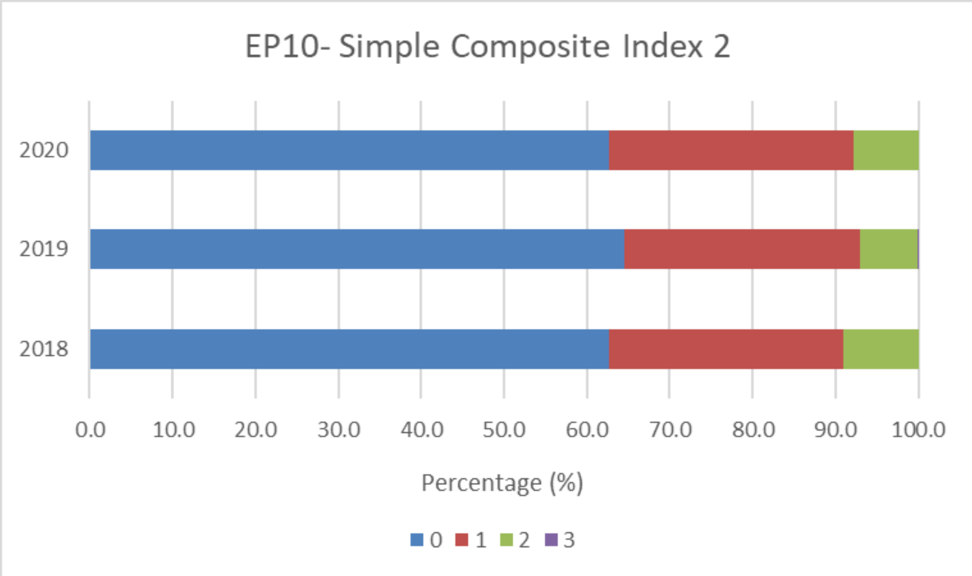


Figure 101. Share of population at EP according to SCI2

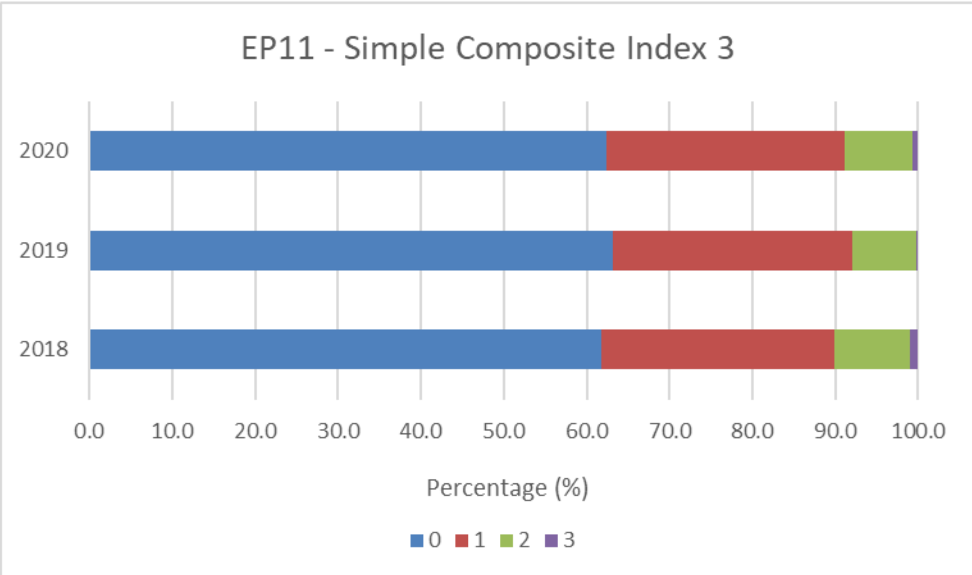


Figure 102. Share of population at EP according to SCI3

The percentage of the population facing any type of EP in the pilot area, i.e., inability to keep their house adequately warm, arrears on utility bills, or leaks/damp walls, shows a decreasing trend, according to Figure 103. It is noteworthy that this indicator shows higher rates of energy poverty, as it combines all individual energy poverty indicators.

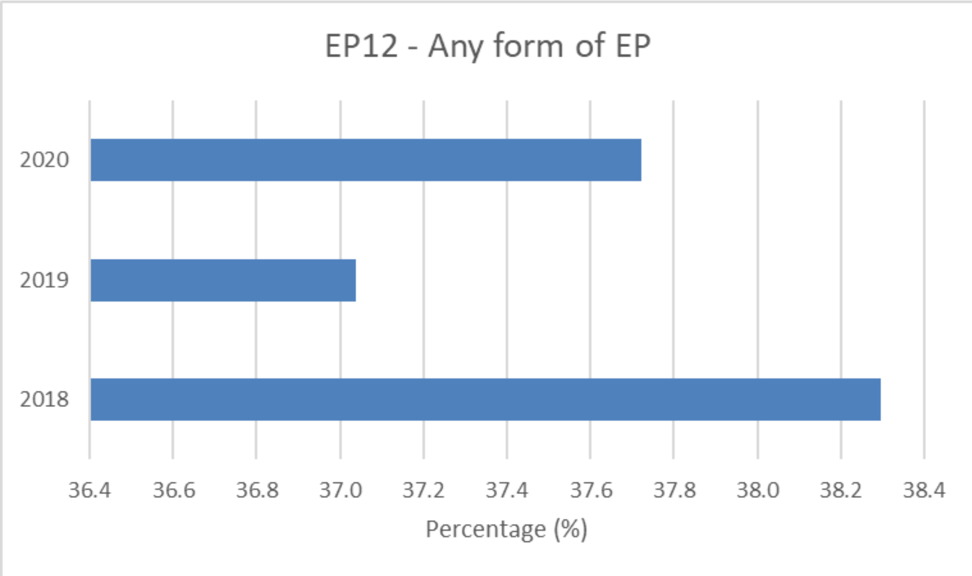


Figure 103. Share of population at EP according to EP12

Below, the relationship between EP vulnerability and certain housing features, as well as living conditions, is explored. As shown in Figure 104, households living in semi-detached houses face the highest problems with leaks/damp walls, while they are less prone to arrears, and they are more capable to keep their house adequately warm. Households living in apartments (small buildings, followed by large buildings) present lower EP issues, on average, as compared to the average rates.

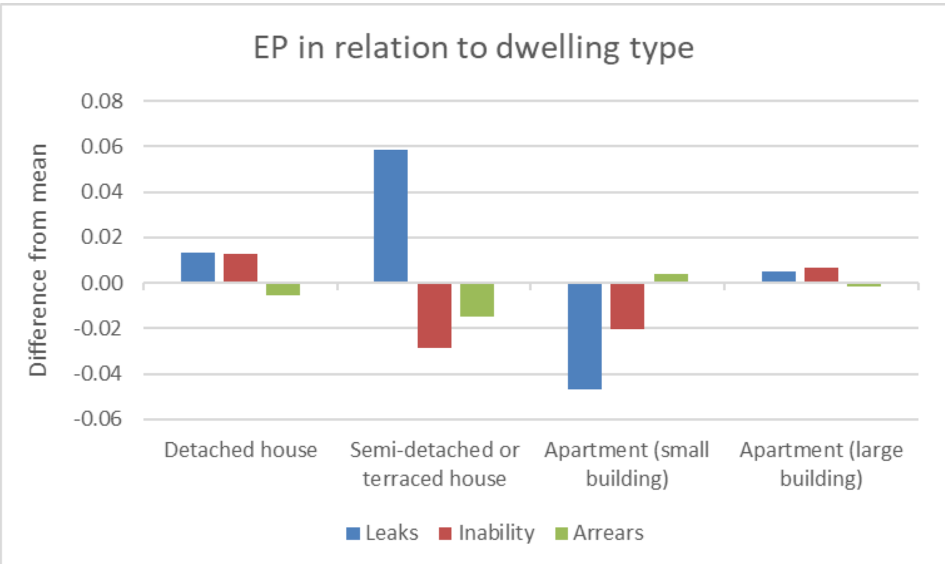


Figure 104. Leaks, inability to keep house warm and arrears on utility bills in relation to dwelling type

The dwelling size is also related to the three basic EP indicators, as shown in Figure 105. Households living in one-room house present the highest problems in terms of leaks/damp walls compared to the average, while they are less prone to the other two indicators, on average. Households living in houses with four or more rooms have the lowest EP rates, probably due to the income of these households.

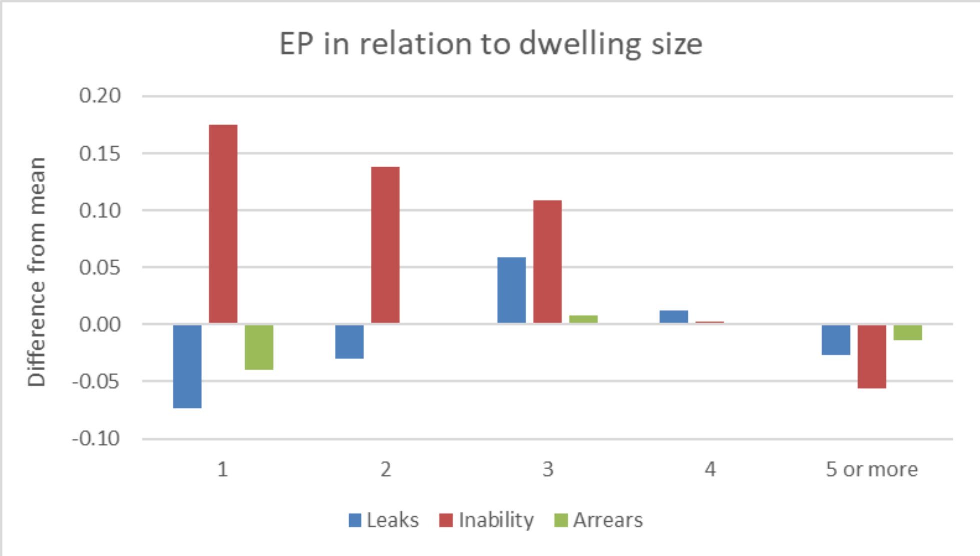


Figure 105. Leaks, inability to keep house warm and arrears on utility bills in relation to dwelling size

Regarding tenure status (Figure 106), the most vulnerable groups to EP are tenants who pay rent (either at market or at reduced rate) and households living at free accommodation. It should be noted though that tenants who pay rent at reduced rate are the most vulnerable ones in terms of keeping their home adequately warm.

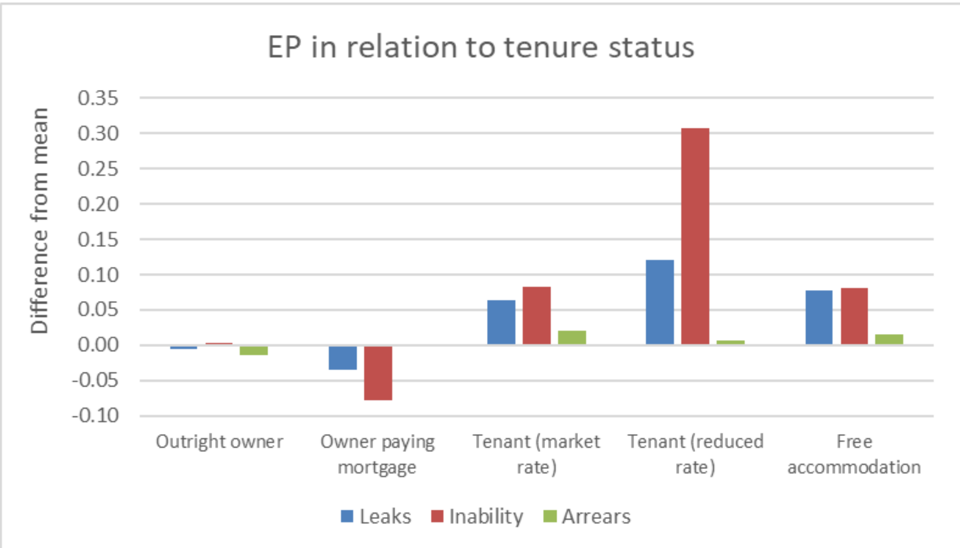


Figure 106. Leaks, inability to keep house warm and arrears on utility bills in relation to tenure status

Figure 107 shows that households experiencing difficulty and great difficulty in making ends meet face also higher EP issues, with differences in EP rates of up to 25% in comparison with average rates. On the other hand, households that can easily make ends meet present quite lower EP rates, of up to 15% versus average rates.

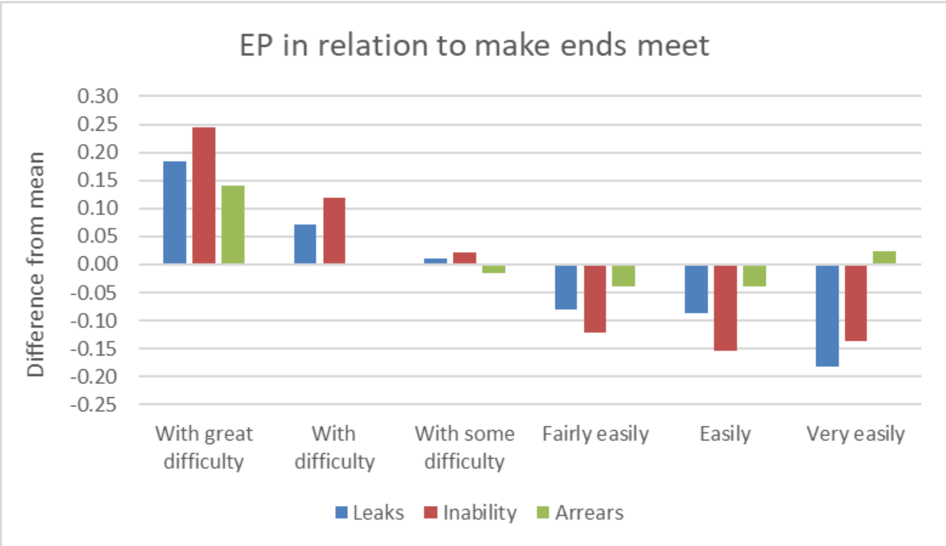


Figure 107. Leaks, inability to keep house warm and arrears on utility bills in relation to the level of difficulty in making ends meet

As regards complementary EP indicators and certain housing features examined, it is shown that households living in small buildings are less prone to EP problems compared to the average rates (Figure 108), while households living in two and three-room houses are more energy vulnerable (Figure 109). Tenants and those living at free accommodation status face higher EP issues (Figure 110), as also happens with households that face difficulty to make ends meet (Figure 111).

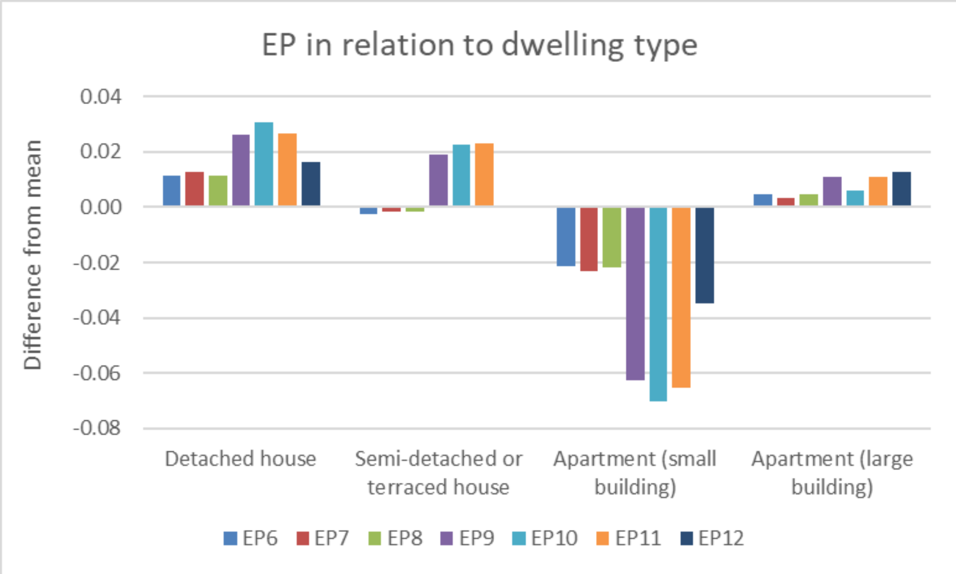


Figure 108. Complementary EP indicators in relation to dwelling type

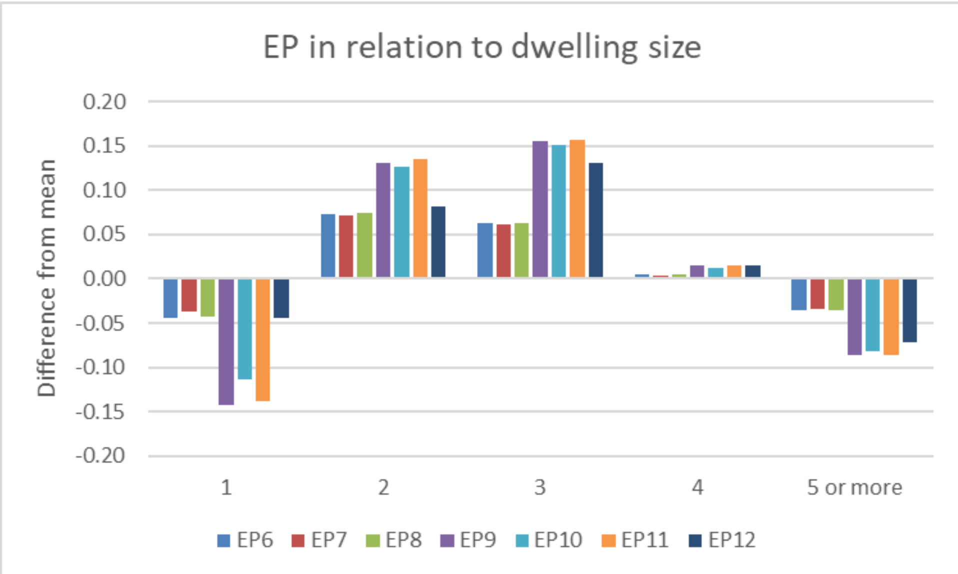


Figure 109. Complementary EP indicators in relation to dwelling size

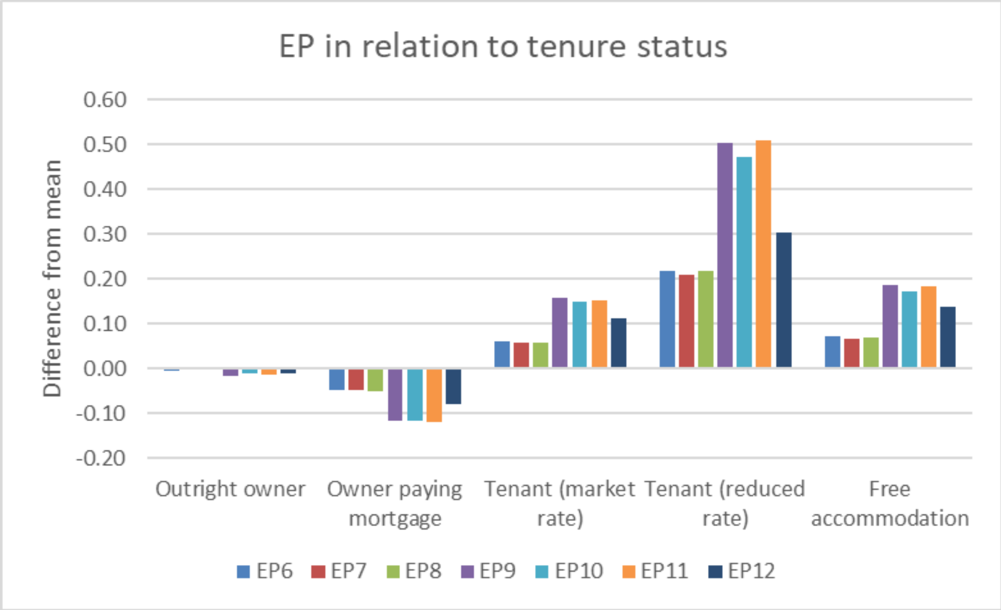


Figure 110. Complementary EP indicators in relation to tenure status

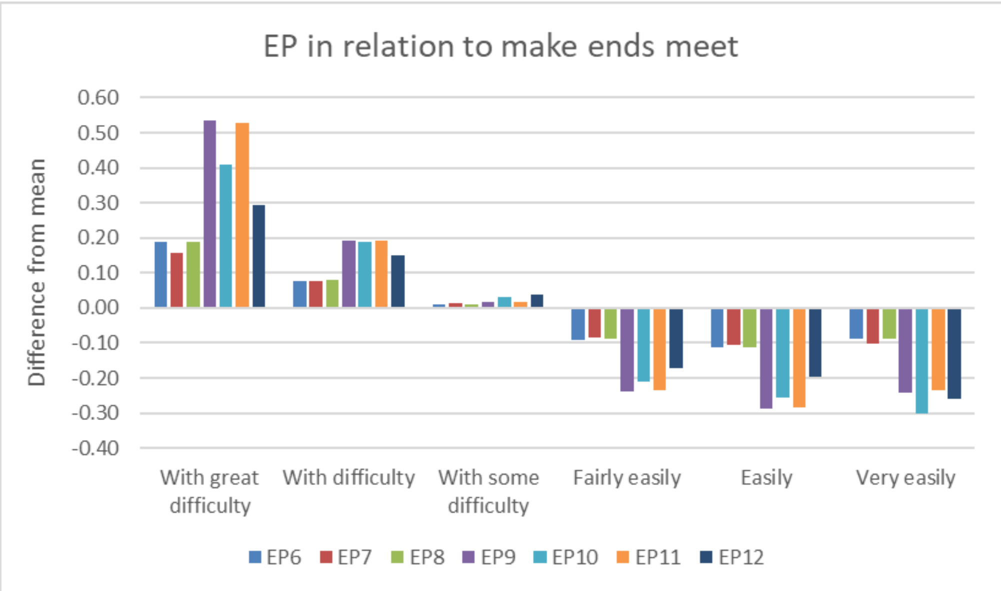


Figure 111. Complementary EP indicators in relation to the level of difficulty in making ends meet

References

Brandão de Vasconcelos, A., Pinheiro, M. D., Manso, A., & Cabaço, A. (2015). A Portuguese approach to define reference buildings for cost-optimal methodologies. *Applied Energy*, *140*, 316–328. https://doi.org/10.1016/j.apenergy.2014.11.035

Eurostat. (2023a, February 2). *Cooling and heating degree days by NUTS 3 regions—Monthly data*. Eurostat - Statistics. https://ec.europa.eu/eurostat/databrowser/view/nrg_chddr2_m__custom_7842696/default/table?lang=en

Eurostat. (2023b, February 22). *Gross domestic product (GDP) at current market prices by NUTS 3 regions*. Eurostat - Statistics. https://ec.europa.eu/eurostat/databrowser/view/nama_10r_3gdp__custom_7843791/default/table?lang=en

Founda, D., & Pierros, F. (2021, February 26). *The 'new' climate of Athens—Period 1991-2020*. Kosmos. http://magazine.noa.gr/archives/4446

Hellenic Ministry of Environment and Energy. (2022). *Energy inspections of buildings, heating and air conditioning systems—Statistical analysis for the year 2021 and the period 2011-2021* (p. 44). Hellenic Ministry of Environment and Energy. https://bpes.ypeka.gr/wp-content/uploads/2022_06_30_E%CE%A4%CE%97%CE%A3%CE%99%CE%91_%CE%95%CE%9A%CE%98%CE%95%CE%A3%CE%97_%CE%A3%CE%A4%CE%91%CE%A4%CE%99%CE%A3%CE%A4%CE%99%CE%9A%CE%A9%CE%9D_%CE%91%CE%A0%CE%9F%CE%A4%CE%95%CE%9B%CE%95%CE%A3%CE%9C%CE%91%CE%A4%CE%A9%CE%9D.pdf

Hellenic Statistical Authority. (2023a). *Population-housing census results 2021*. https://elstat-outsourcers.statistics.gr/Booklet_%CE%91%CF%80%CE%BF%CF%84%CE%B5%CE%BB%CE%B5%CF%83%CE%BC%CE%B1%CF%84%CE%B1%CE%A0%CE%BB%CE%B7%CE%B8%CF%85%CF%83%CE%BC%CE%BF%CF%852023_II%20GR_FINAL2_WEB.pdf

Hellenic Statistical Authority. (2023b). *Census Results of Population and Housing 2021*. Hellenic Statistical Authority. https://www.statistics.gr/en/2021-census-res-pop-results

Magalhães, S. M. C., & Leal, V. M. S. (2014). Characterization of thermal performance and nominal heating gap of the residential building stock using the EPBD-derived databases: The case of

Portugal mainland. *Energy and Buildings*, *70*, 167–179. https://doi.org/10.1016/j.enbuild.2013.11.054

Menyhert, B. (2023). *Energy poverty—New insights for measurement and policy* [Scientific analysis or review]. European Commission.

Monzón-Chavarrías, M., López-Mesa, B., Resende, J., & Corvacho, H. (2021). The nZEB concept and its requirements for residential buildings renovation in Southern Europe: The case of multi-family buildings from 1961 to 1980 in Portugal and Spain. *Journal of Building Engineering*, *34*, 101918. https://doi.org/10.1016/j.jobe.2020.101918

Palma, P., Gouveia, J. P., & Simoes, S. G. (2019). Mapping the energy performance gap of dwelling stock at high-resolution scale: Implications for thermal comfort in Portuguese households. *Energy and Buildings*, *190*, 246–261. https://doi.org/10.1016/j.enbuild.2019.03.002

Sousa, J., Bragança, L., Almeida, M., & Silva, P. (2013). Research on the Portuguese Building Stock and Its Impacts on Energy Consumption – An Average U-Value Approach. *Archives of Civil Engineering*, *59*. https://doi.org/10.2478/ace-2013-0029

Vicente, R., Varum, H., & Mendes da Silva, J. A. R. (2006, September 3). *Vulnerability assessment of traditional buildings in Coimbra, Portugal, supported by a GIS Tool*. First European Conference on Earthquake Engineering and Seismology, Geneva, Switzerland. https://ria.ua.pt/bitstream/10773/8128/1/I_036.pdf

Annex II: Social surveys in REVERTER pilots

Table of Contents

List of Figures

List of Tables

1 Pilot 1 - Brezovo (Bulgaria)

1.1 Survey administration

Information was collected between May 18th and June 29th, 2023, via an online surveying platform (Google drive) and face-to face survey. The target group was households residing in Municipality of Brezovo, and only individuals 18 years of age or older could participate in the survey. The survey was communicated through two different channels:

(a) Facebook page of Municipality of Brezovo

(b) Official website of Municipality of Brezovo

In total, 350 surveys were collected (online and face to face), from which 300 were validated as correct and updated in Google Drive. Many residents were reluctant to take part in the survey. Some of them were distrustful and sceptical, thinking that the National Recovery and Resilience Plan wouldn't help to substantially relieve the households' energy poverty issues. Furthermore, some residents of the municipality shared their inability to benefit from the National plan, as they have to finance the solar panel systems or domestic hot water supply unit themselves. Others were uninterested and indifferent. In order to persuade inhabitants to take part in the survey, patience, time and clarifications were needed and used. However, there were some open-minded participants that already knew about the National plan and had already purchased solar systems and/or solar-powered hot water supply units for their households and were happy to participate in the survey.

1.2 Demographics

The main demographic characteristics are presented in Table 1 and are summarised below.

51% of the respondents were female and 46% were male. The majority of the respondents (26%) were between 50 and 59 years old, 16% were between 40 and 49 years old, 14% were between 60 and 69 years old, and 12% were between 70 and 79 years old, 11% were between 30 and 39 years old. Also, 4% were more than 80 years old and 3% were between 20 and 29 years old, i.e., younger households are underrepresented in the sample.

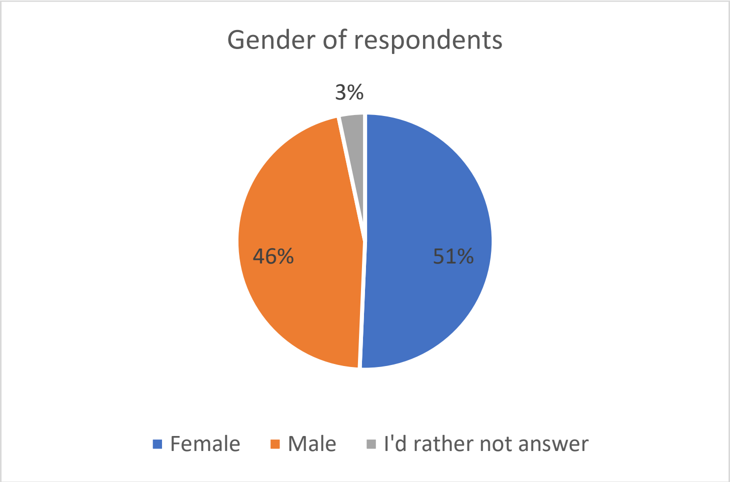


Figure 1. Gender of respondents

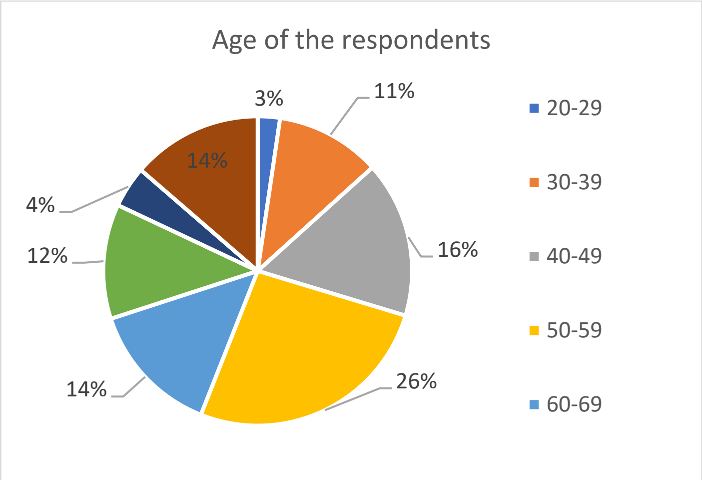


Figure 2. Age of the respondents

As far as the educational level is concerned, 1% have only primary school level, 5% have not completed primary school, 6% have Secondary school level, 5% have Post-secondary vocational degree, 16% have Secondary vocational degree, 26% has access to tertiary education. 1% have incomplete primary school. The majority of the respondents prefers not to answer about their education level.

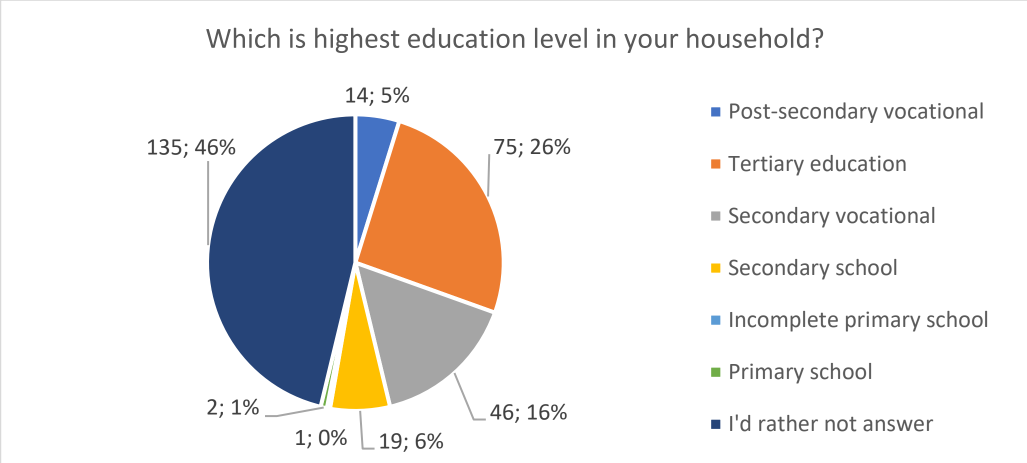


Figure 3. Education level

As regards to the number of persons in the household, most of the households (about 32%) include two persons, 22% three persons, 15% include 4 persons, 11% include only one person, 7% of the households include 5 persons. There are 3% households with 6 or more persons. Only 31 respondents (10%) indicated that there are children in the households and 24% of the households have students. 21% of the answered households have at least one and 23% of the households have 2 residents who are retired, again huge part of the respondents (50%) rather not to answer about the number of pensioners in the household. 12% of households indicated that at least one household member of any age with a disability or long-term illness and 80% of the respondents prefer not to answer.

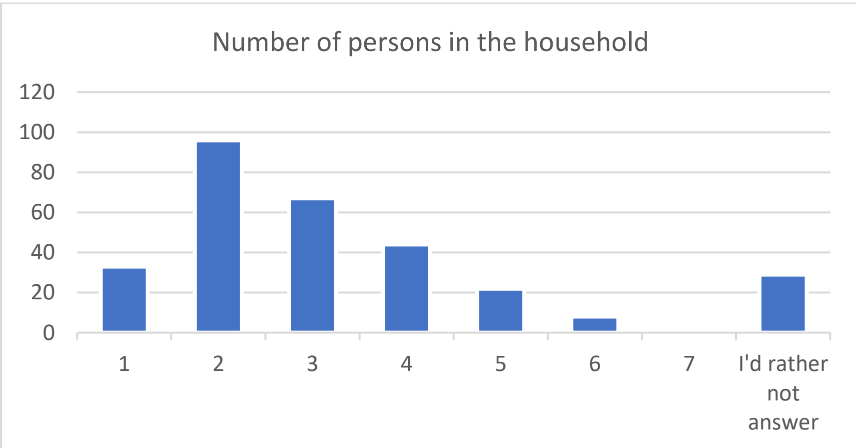


Figure 4. Number of persons in the household

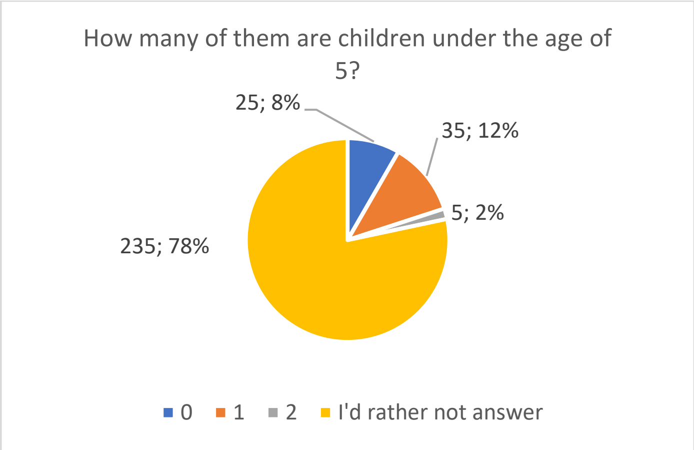


Figure 5. Number of children under the age of 5

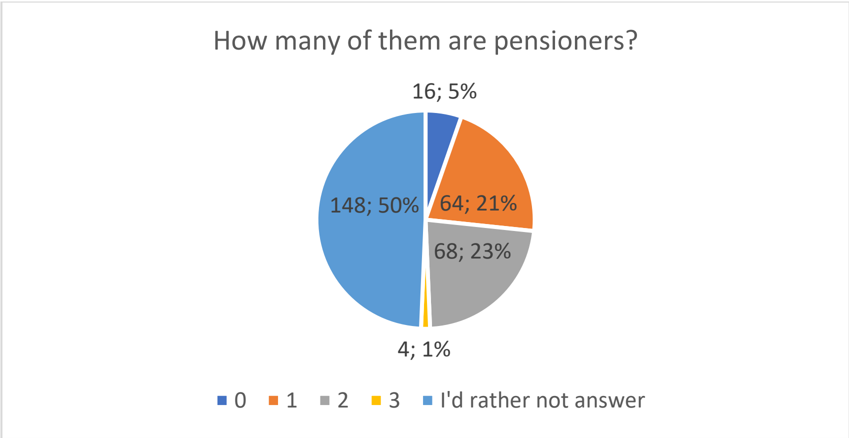


Figure 6. Number of pensioners in the household

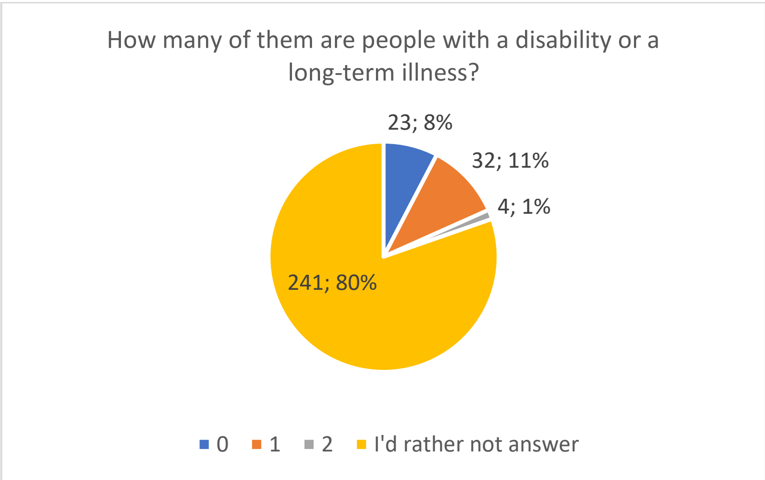


Figure 7. Number of people with disability or a long-term illness

Table 1. Sample demographics – Brezovo survey

Gender	Female	51
	Male	46
	Prefer not to answer	3
Age class	20-29	2%
	30-39	11%
	40-49	16%
	50-59	26%
	60-69	14%
	70-79	12%
	80-89	4%
	Prefer not to answer	14%
Household members	1	11%
	2	32%
	3	22%
	4	15%
	5	7%
	6	3%
	7	0%
	I'd rather not answer	10%
HH with children less than 5 years old	0	8%
	1	12%
	2	2%
	I'd rather not answer	78%
HH with students	0	8%
	1	15%
	2	9%
	3	0%
	I'd rather not answer	68%
HH with pensioners	0	5%
	1	21%
	2	23%
	3	1%
	I'd rather not answer	49%
Full-time employed HH members	0	9%
	1	4%
	2	3%
	I'd rather not answer	85%
Long-term unemployed HH members	0	0%
	1	3%
	2	1%
	I'd rather not answer	96%
HH members with disabilities/long-term illness	0	8%
	1	11%
	2	1%
	I'd rather not answer	80%
Educational level	Post-secondary vocational	5%
	Tertiary education	26%
	Secondary vocational	16%
	Secondary school	7%
	Incomplete primary school	0%
	Primary school	1%
	I'd rather not answer	46%

Focusing on household economic status-related aspects, most of the households (12%) indicated that their income (including allowances, rental income, etc.) is between 301-600 EUR. 9% of the households indicated that their income is between 901-1200EUR and 8% indicated income between 601-900 EUR. Again, most of the respondents (60%) prefer not to answer.

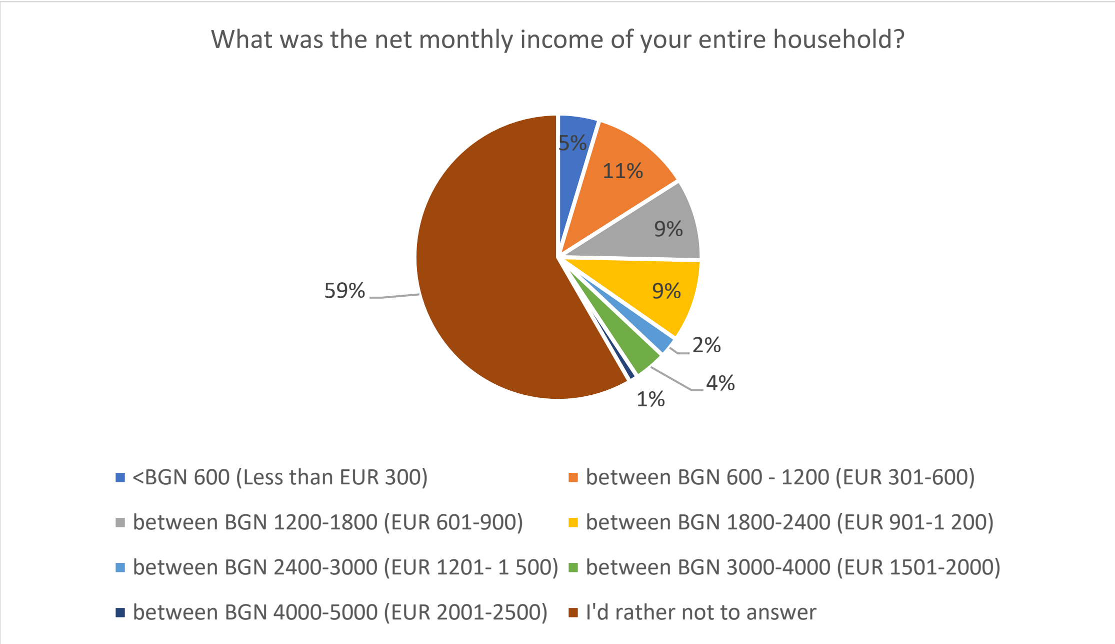


Figure 8. Monthly income

According to Figure 9, 17% of the respondents don't know what their monthly expenditure are, 6% stated that their expenditure is between 501-750EUR and 5% have between 200-500EUR.

Asked about how they would describe their current income, 60% of the households answered that they are coping on their current income, while 21% indicated that they are finding very difficult to live on current income, only 5% stated that they are living comfortably on their income. 69% of the respondents prefer not to answer.

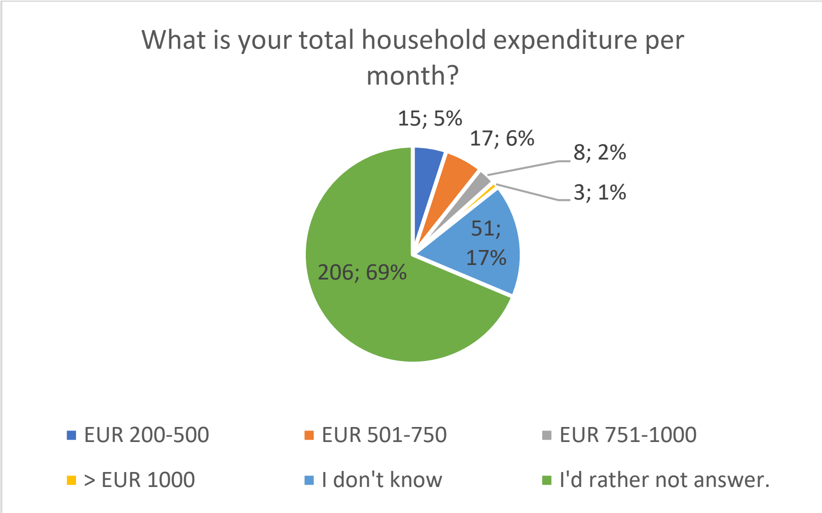


Figure 9. Household expenditure per month

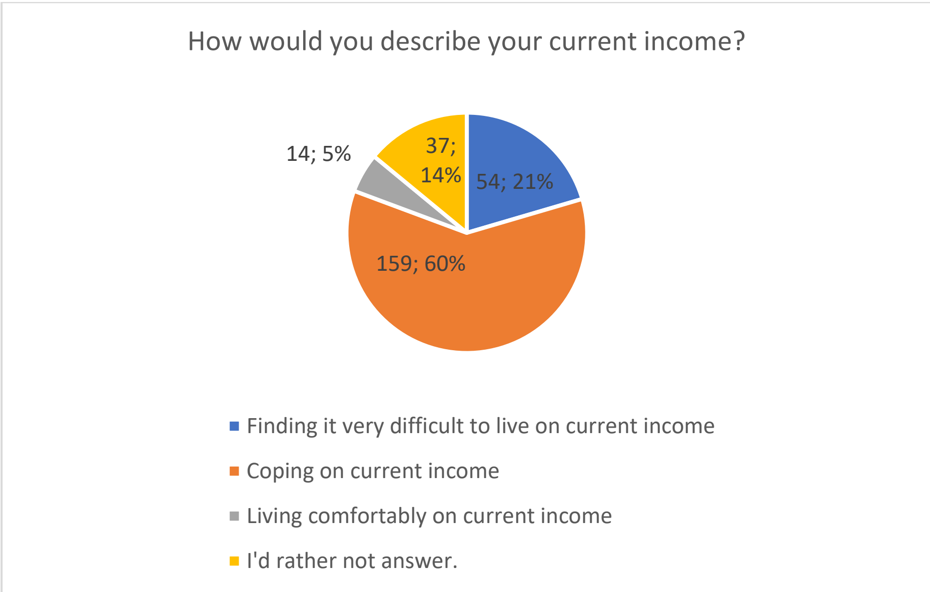


Figure 10. Household current income description

Regarding the employment, most of the respondents prefer not to answer (85%), 9% of the households don't include full-time employed person and per 3% have one or two employed persons. As far as the number of people with a disability or a long-term illness are concerned, 80% of the respondents prefer not to answer. About 11% of the households have one person with disability and 8% don't have such person.

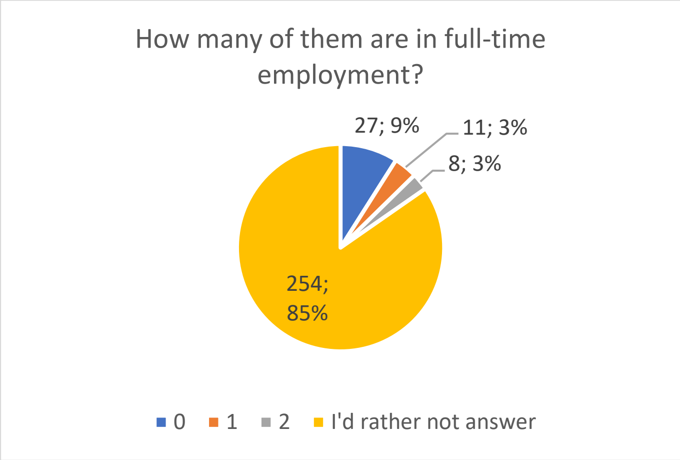


Figure 11. Number of full-time employment people

1.3 Housing characteristics

As it can be seen in Figure 12, about 55% of respondents live in detached houses with two levels and 35% live in detached houses on one level. 10% of the respondents are living in are apartments. Most of the apartments (5%) are on the first floor of the building, followed by apartments in the intermediate floor of the building (3%) and the top floor (2%).

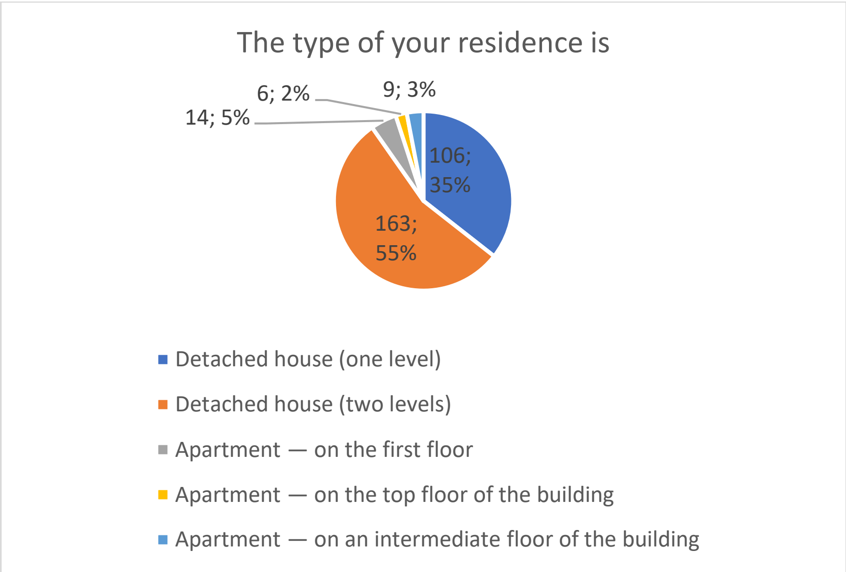


Figure 12. Type of the residence

As shown in Figure 13, the largest share of the existing residential building stock (29%) was created before 1949. 15% of the buildings were created between 1950-1959. 31 % of the buildings were created in the period 1960-1989 – in this period, for the first time, requirements were set for the energy efficiency in buildings through normative coefficients of heat transfer of the enclosing building elements (external walls, floor, roof).

In the period 1990-1999, 11% of the inhabited residential buildings were built.

After 2000, with the entry into force of modern and highly demanding normative documents for EE, only 3% of the residential buildings were put into operation. 11% of the respondents answered that they don't know about the year of construction of their building.

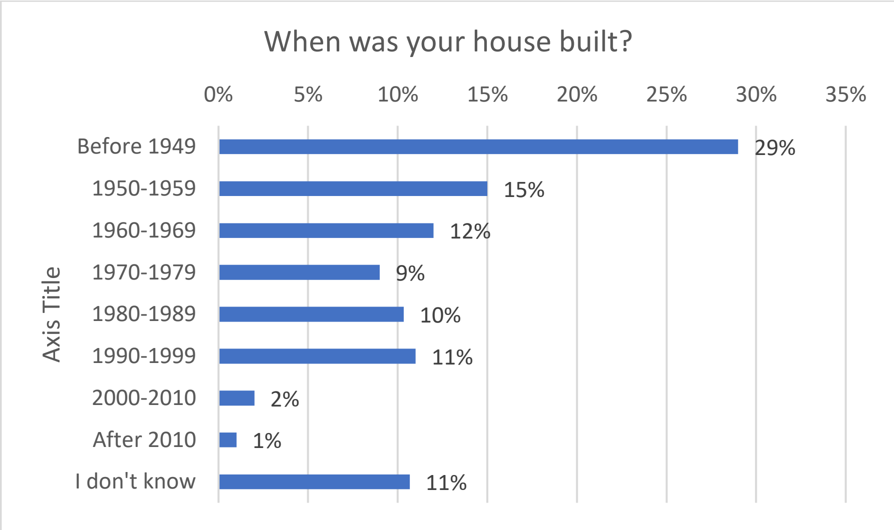


Figure 13. Construction year of dwellings

Regarding the living area, 42% of the dwellings are more than 160m^2, 16% are between 100-119m^2, 16% are between 120-139m^2, 6% are with 80-89m^2, 5% are with 140-159m^2, respectively per 4% are dwellings with 70-79 and 60-69m2. The rest are under 59m^2.

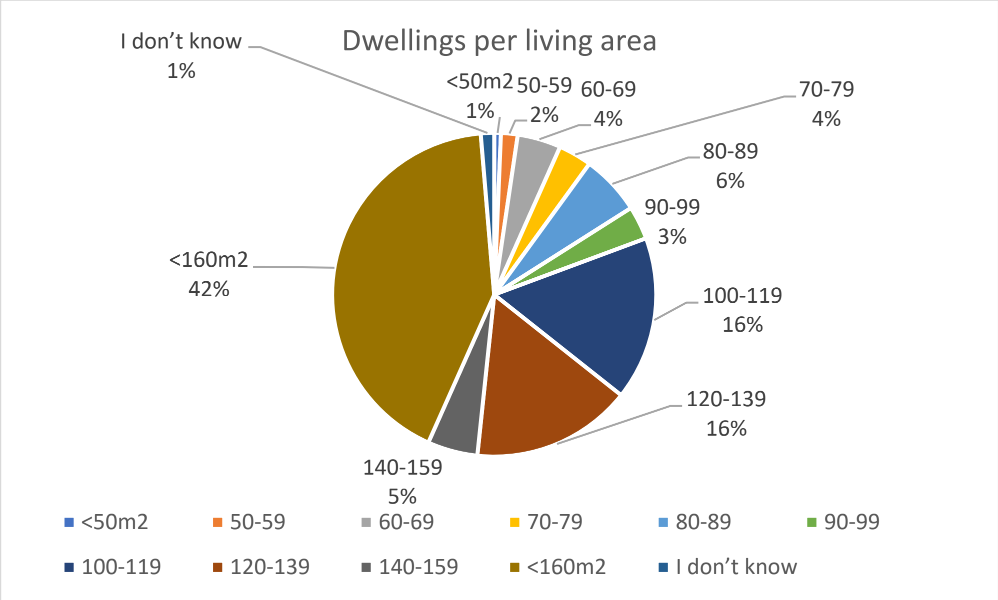


Figure 14. Dwellings per living area

As regards to the number of rooms, most of the dwellings (38%) have four rooms, 20% have six rooms, 15% have five rooms and 13 % have three rooms. The rest of the dwellings (16%) have more than six rooms (Figure 15).

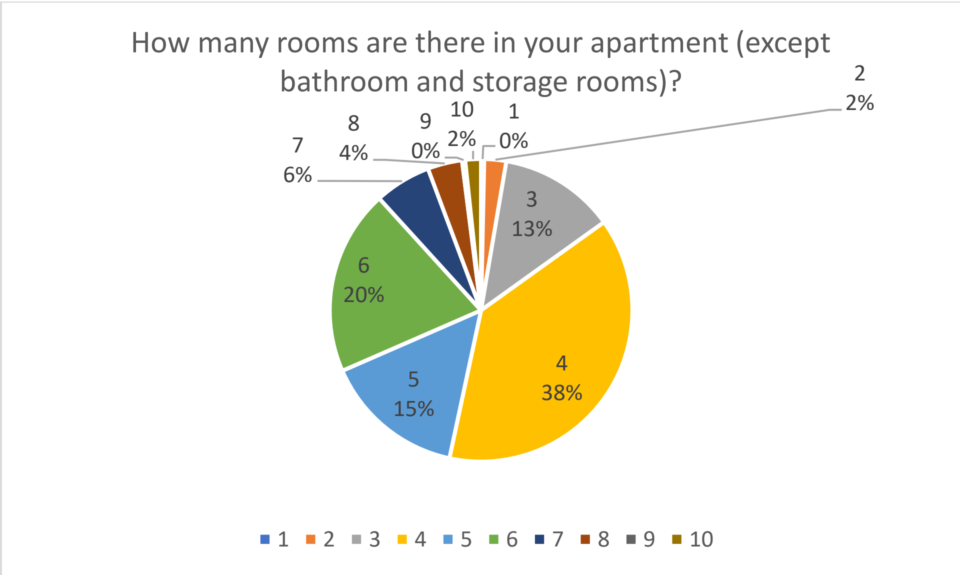


Figure 15. Dwellings per number of rooms

Finally, as shown in (Figure 16), most dwellings (i.e., 94%) are privately owned without financial obligations. Privately owned dwellings with financial obligations (loan, mortgage, etc.) are 3%. A small percentage of dwellings (1%) have been provided free of charge by family, friends, employers, or other.

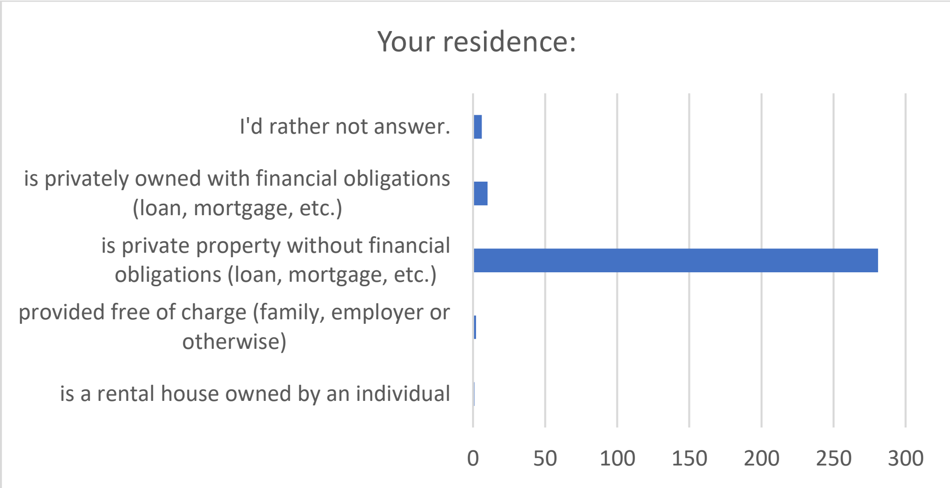


Figure 16 Type of the ownership

1.4 Mechanical systems

Regarding the main heating source (Figure 17), most of the respondents (41%) have indicated that they are heated with air conditioners, followed by heating with Firewood/pellets stoves (26%). Around 12% of the respondents use Central heating with firewood/pellets. About 4% are heated by individual electrical devices and another 4% use individual liquid fuel stoves.

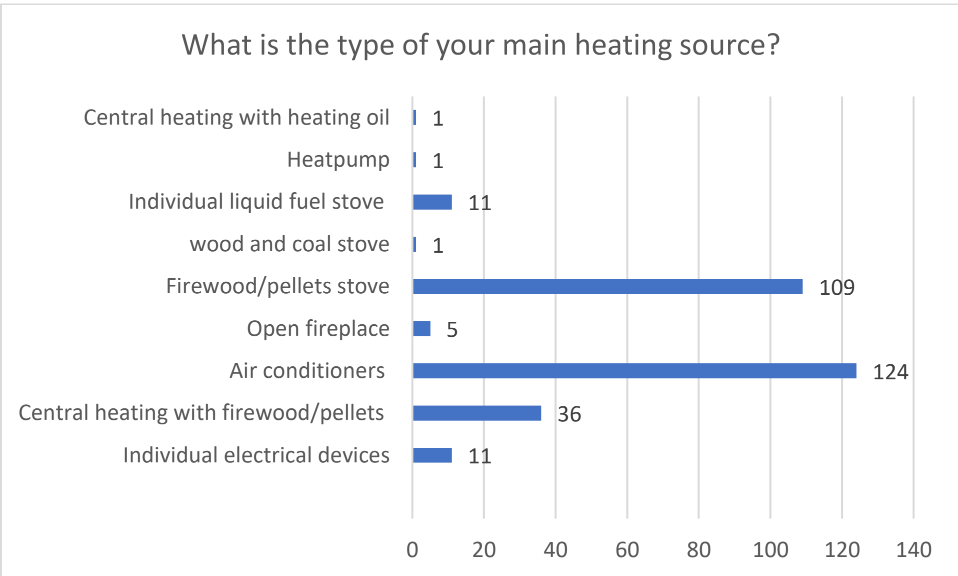


Figure 17. Type of the main heating source

It is interesting to note that 53% of the respondents have supplementary heating source. About 29% of those who are using air conditioners as primary heating source have additional heating sources as wood/pellets stoves, electrical devices or open firewood. Furthermore, 7% of the respondents use electrical devices additional heating source and 28% of the respondents use air conditioner as supplementary heating source.

According to Figure 18, those who are finding it very difficult to live on current income rely mainly on individual firewood/pellet stoves, air conditioners, and open fireplaces. That is, they most probably heat only part of their homes and use (as far as the open fireplaces and firewood/pellet stoves are concerned) heating systems that degrade indoor air quality.

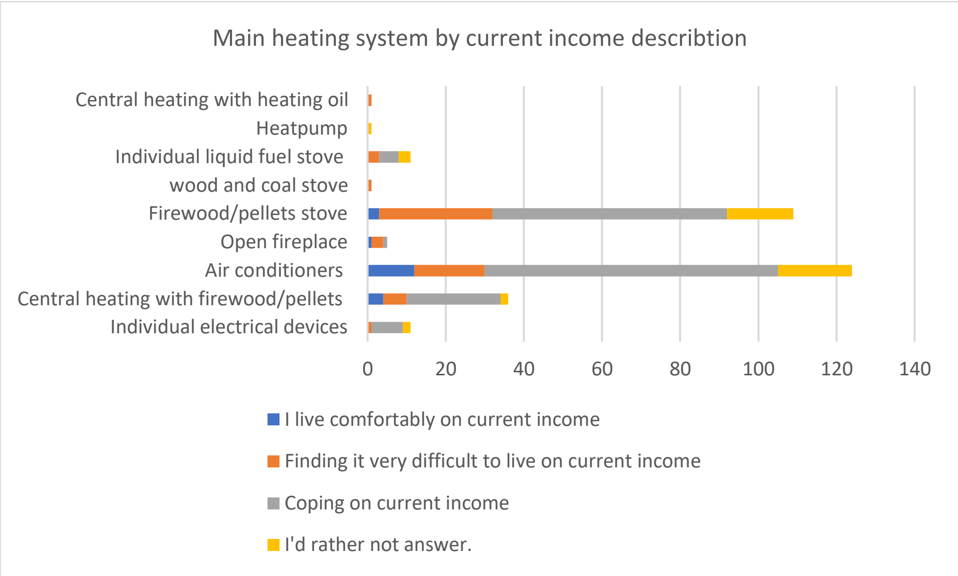


Figure 18. Main heating system by current income description

1.5 Energy costs and habits

In regards with the heating operation hours per day it can be seen in Figure 19, that most of the households (about 39%) operate their heating system more than 10 hours and 38% between 6 and 10 hours per day. Furthermore, 10% operate their heating system between 4 and 6 hours and 5% indicated that the system is on 24 hours a day with a thermostat at a certain temperature.

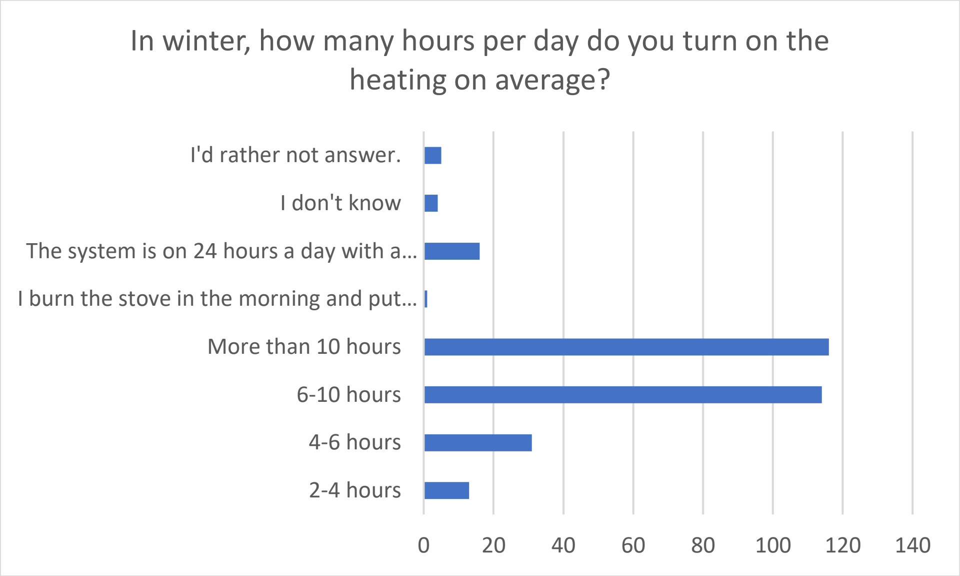


Figure 19. Operating hours of heating system

When asked about the optimal indoor temperature, 69% of the respondents answered >21°C and 18% answered between 18-21°C. As seen in Figure 20, 65% of the respondents keep temperature higher than 21°C and 22% keep between 18-21 °C. 6% keep between 15-18°C and only 1% do not reach 15°C. 5% of the respondents have indicated that they don't know what the heating temperature in their home is.

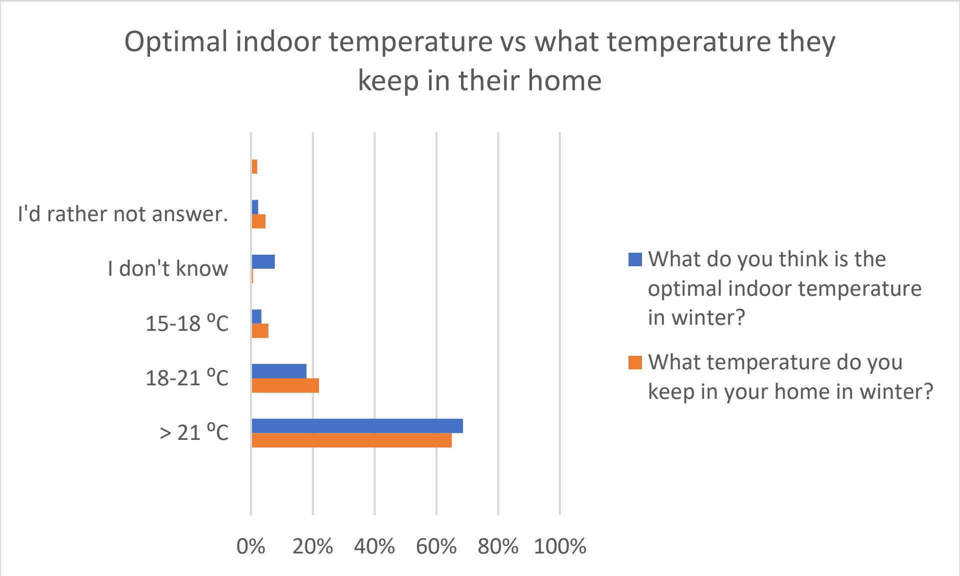


Figure 20. Optimal indoor temperature vs. what temperature they keep in their home

The following figure shows the relationship between the number of people who answered that they experience health problems caused by a suboptimal temperature in the home and the actual temperature maintained. It can be seen that 50% of the respondents that keep temperature below 15°C noticed health problems. Moreover, 25% of the respondents that keep temperature between 15-18° also face any health problems related to internal conditions.

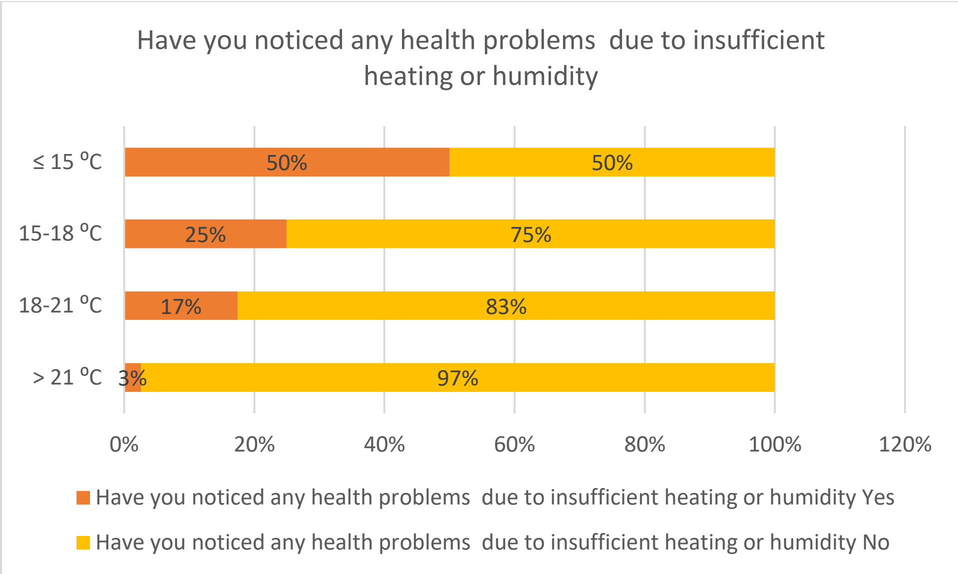


Figure 21. Health problems due to insufficient heating in relation to home temperature

The following figure summarises the survey responses around electricity-related awareness and behavioural issues. More than a half of the respondents (56.8%) stated that they compare electricity consumption with previous years. Again, more than a half read the consumption in the electricity bill, but some of them don't understand the charges (only 47.2% stated that they understand their electricity bills). Only 11% often check the electricity meter reading, which means that further educational actions should be focused on energy monitoring in the households. Still 56.6% follow the energy-saving instructions given by the electricity supplier.

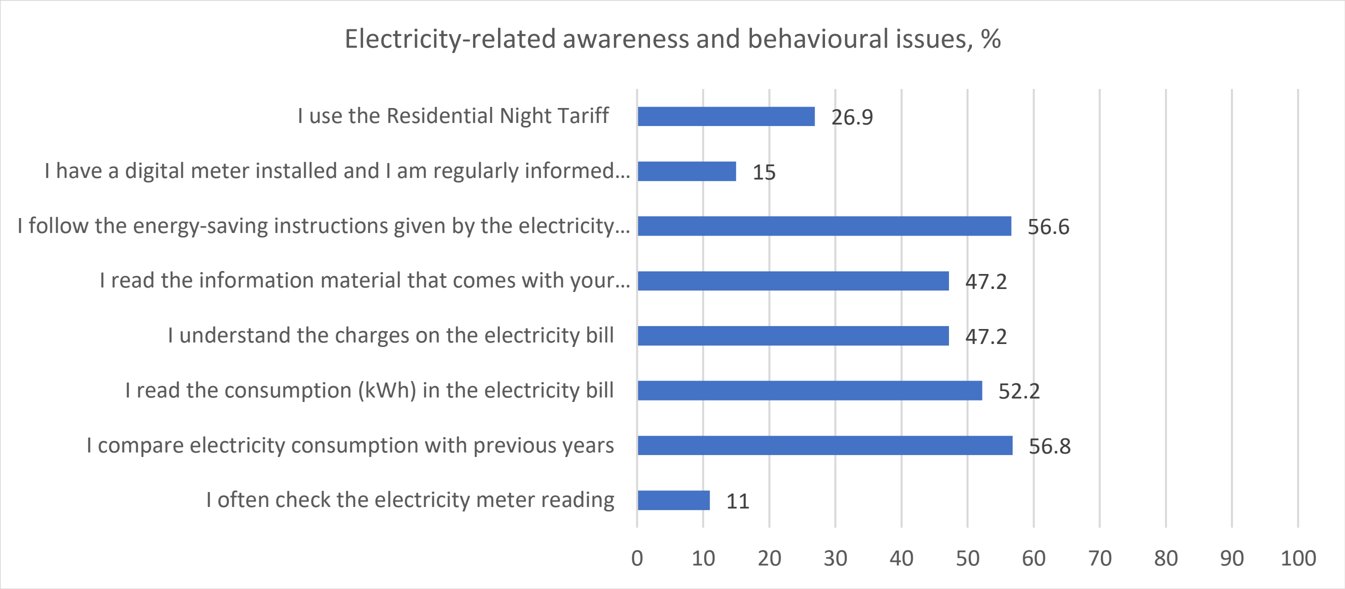


Figure 22. Electricity-related awareness and behavioural issues, %

Regarding the analysis of the monthly electricity bills for winter season, most of the respondents that use air-conditioners for heating are paying between BGN 160-1200 (80-100 EUR/month). A not small part is paying even more – BGN200-300 (100-150 EUR/month).

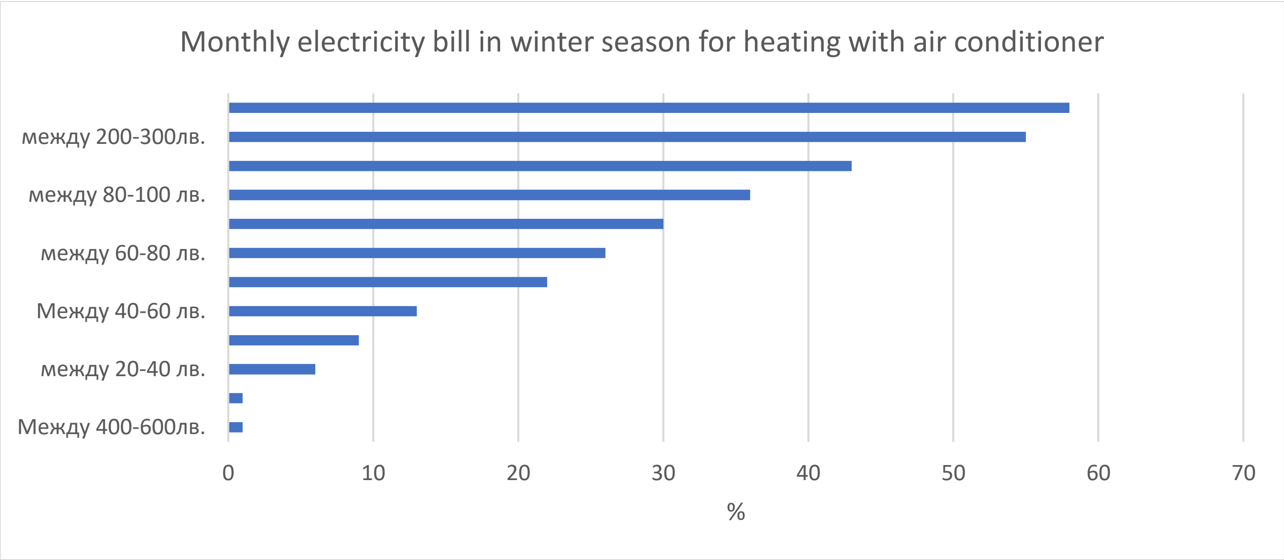


Figure 23. Monthly electricity bill in winter season for heating with air conditioner

Regarding the heating costs for the whole winter season, the analysis shows that most of the respondents pay between BGN 400-700 (200-350 EUR/season). As indicated before, the most common heating source are pellets and woods (by stoves and boilers) and electricity (air-conditioners).

The next figure shows analysis of the average household costs, starting from the total annual energy costs – 2130 BGN (about 1089 EUR). The average annual electricity costs are 1646 BGN or 841 EUR, from which the average electricity costs in summer is 600 BGN (300 EUR) and average electricity in winter 904 BGN (462 EUR). The average total energy costs for heating (electricity plus another energy source) in the winter are 1504 BGN or 769EUR.

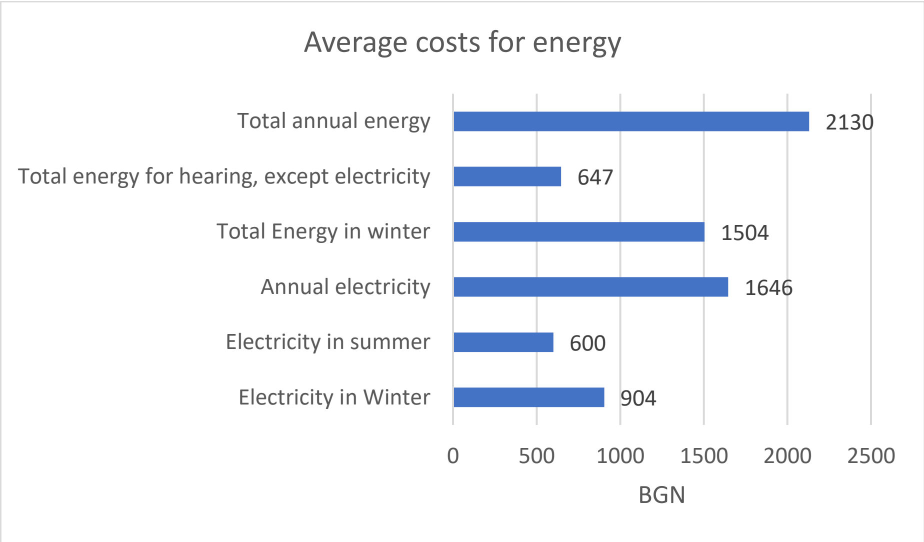


Figure 24. Average costs for energy

Regarding the heating monthly costs in relation with the heating source, it could be concluded, that the average monthly costs for heating is between 400-700 BGN or 200-350EUR. Most of the households use woods or pellets and on the second place are the air-conditioners.

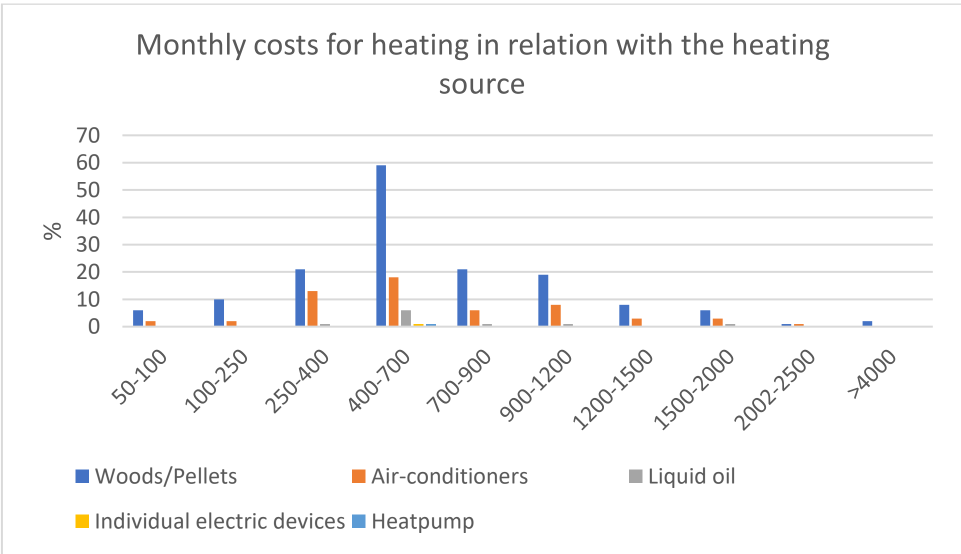


Figure 25. Monthly costs for heating in relation with the heating source

The following figure shows the heating (electricity and total energy) costs for the winter season, depending on the different heating sources. The highest average costs for electricity per season are paying the households using heat pumps (1500 BGN or 750 EUR). The average winter costs per electricity in households using air conditioners for heating are 1192 BGN or about 610EUR. On third place are electricity costs in the households using individual electrical devices – 1152 BGN or 589EUR average costs.

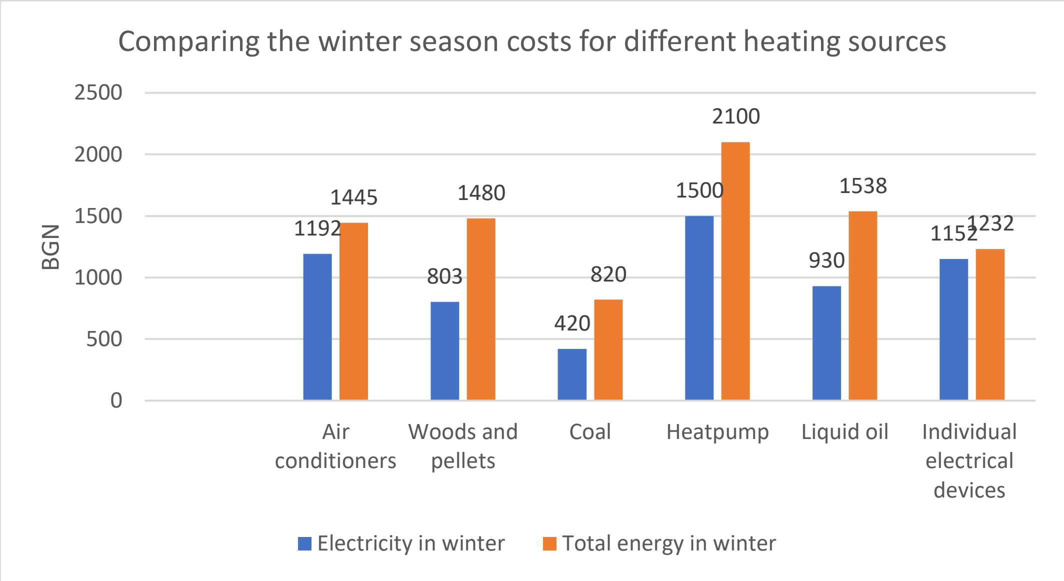


Figure 26. Comparing the winter season costs for different heating sources

According to Figure 27, larger homes require higher energy costs. The energy costs of homes with 2 to 4 rooms are about twice as high as those of homes with 1 room. Also, homes with 5 or more rooms have energy costs increased by 20-30% compared to homes with 2 to 4 rooms.

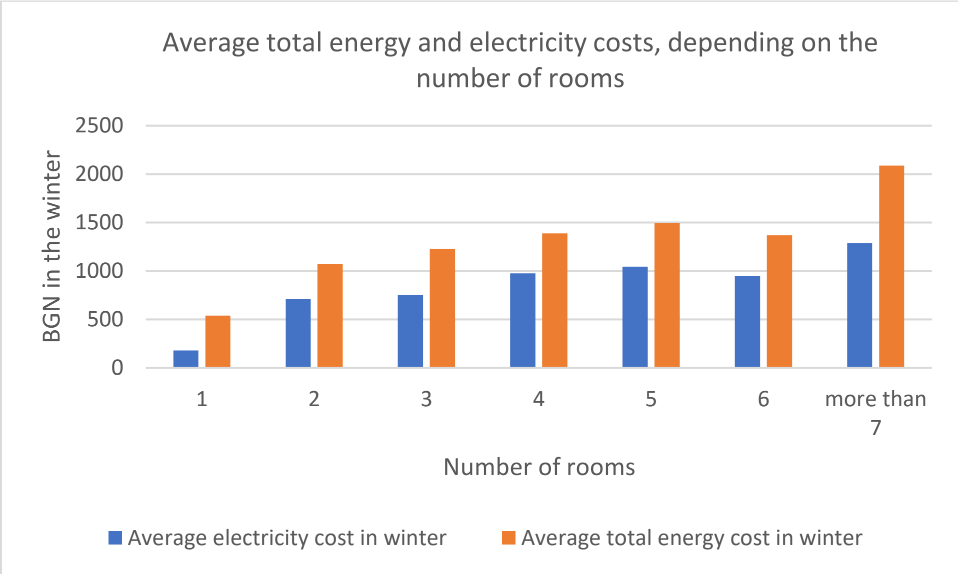


Figure 27. Average total energy and electricity costs, depending on the number of rooms

As shown in the next figure, the energy costs are related to the average temperature of the dwelling. On average, there appears to be a difference of 8% in total energy costs between houses with an average indoor temperature below 15°C and those with an average indoor temperature of 15-18°C, respectively. Also, there is a difference of 10% in total energy costs between houses with an average indoor temperature between 15-18°C and those with an average indoor temperature above 18°C. The difference in energy costs is relatively small compared to the difference in indoor temperature. This may be due to the different energy class of the houses. That is, the houses with the lowest temperatures may be, in principle, low energy-efficient houses, which means that higher expenditure is required to achieve even a lower-than-adequate temperature.

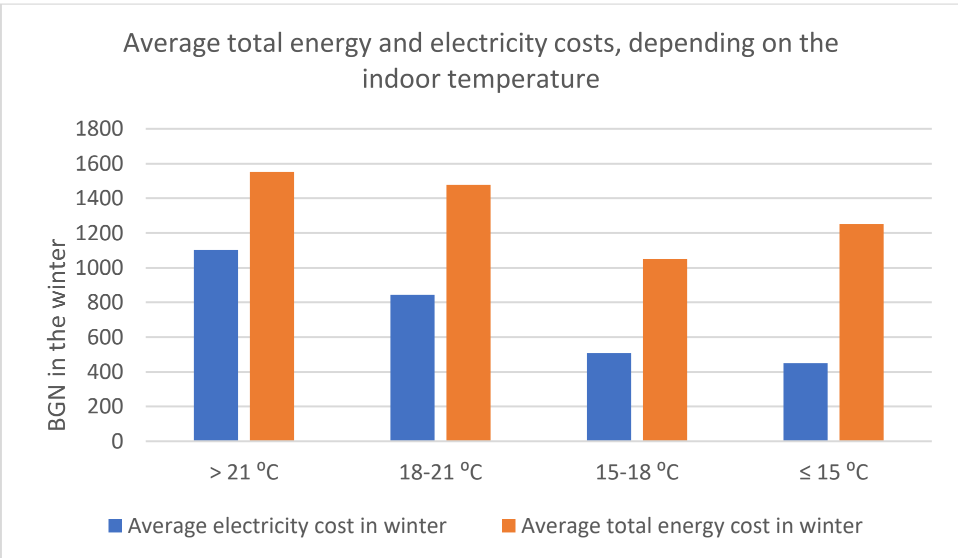


Figure 28. Average total energy and electricity costs, depending on the indoor temperature

Figure 29 shows how the energy expenses are affected by the number of people in the households. The trend line indicates the higher the number of household members the higher the energy costs.

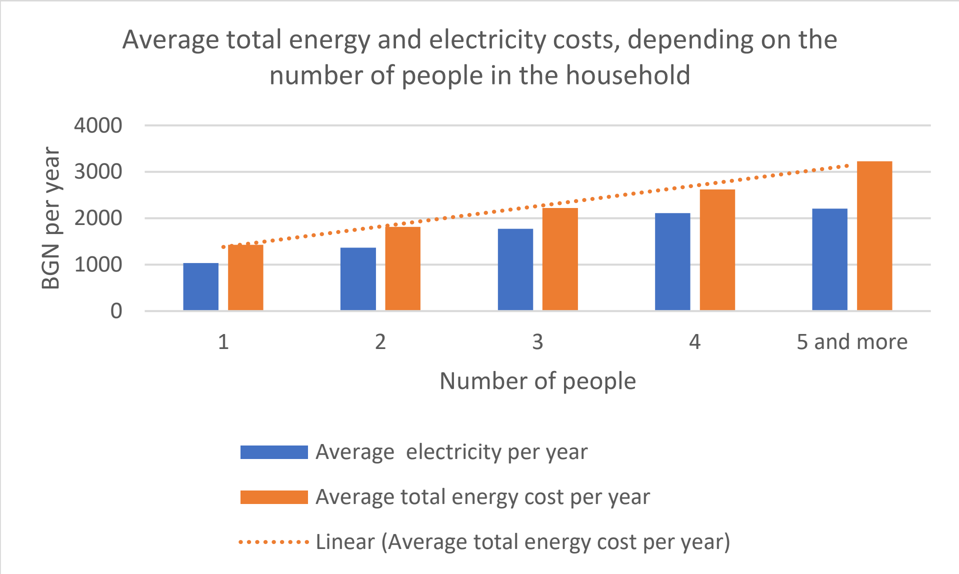


Figure 29. Average total energy and electricity costs, depending on the number of people in the household

Household members characteristics affect the annual energy costs (Figure 30). Households with children less than 5 years old and disabled spent more money to meet their energy needs. Pensioners and unemployed spend less for energy.

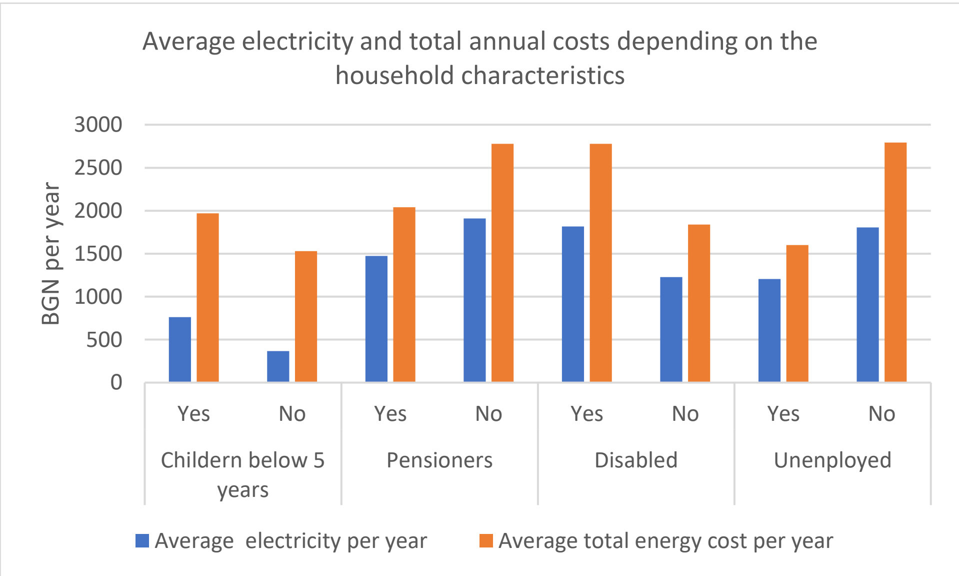


Figure 30. Average electricity and total annual costs depending on the household characteristics

Figure 31 shows that households that find it very difficult to live on their current income spent less than households that coping on the current income or living comfortably. Still, there is no big difference as the energy is necessary acquisition.

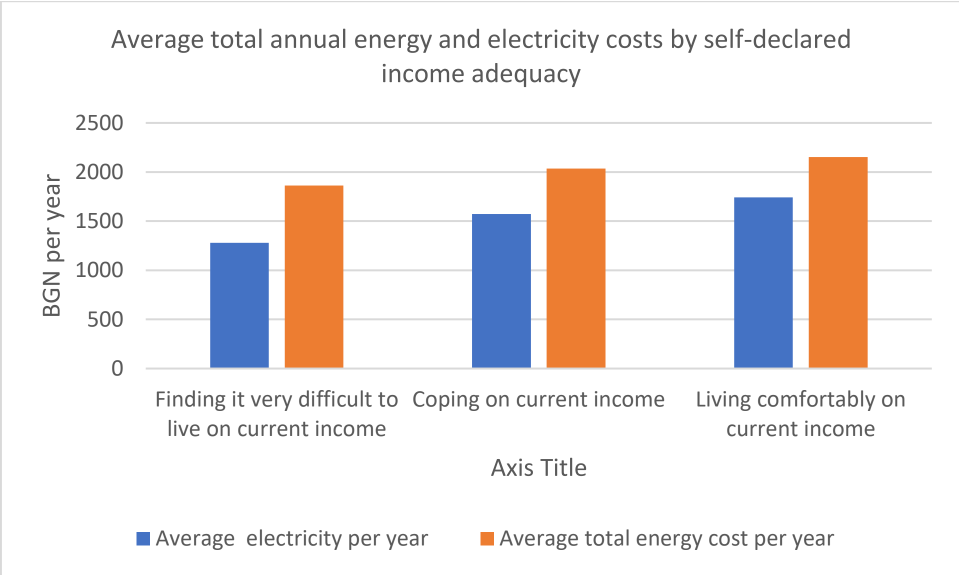


Figure 31. Average total annual energy and electricity costs by self-declared income adequacy

1.6 Energy efficiency interventions and awareness

Respondents were asked about the energy efficiency measures they had implemented in their homes over the past ten years. Most of the households (82%) have implemented new energy efficient windows and doors, but only 40% have wall/ceiling insulation. 63% have installed energy-saving lamps and 39% have new energy efficient appliances. Regarding the RES installations in the households, 4% have installed solar water heater and 7% have PV panels on the roof. Surprisingly, only 3% indicated that they had new heating or cooling sources, but this may be due to deep-seated habits of using wood stoves and reluctance to change habits.

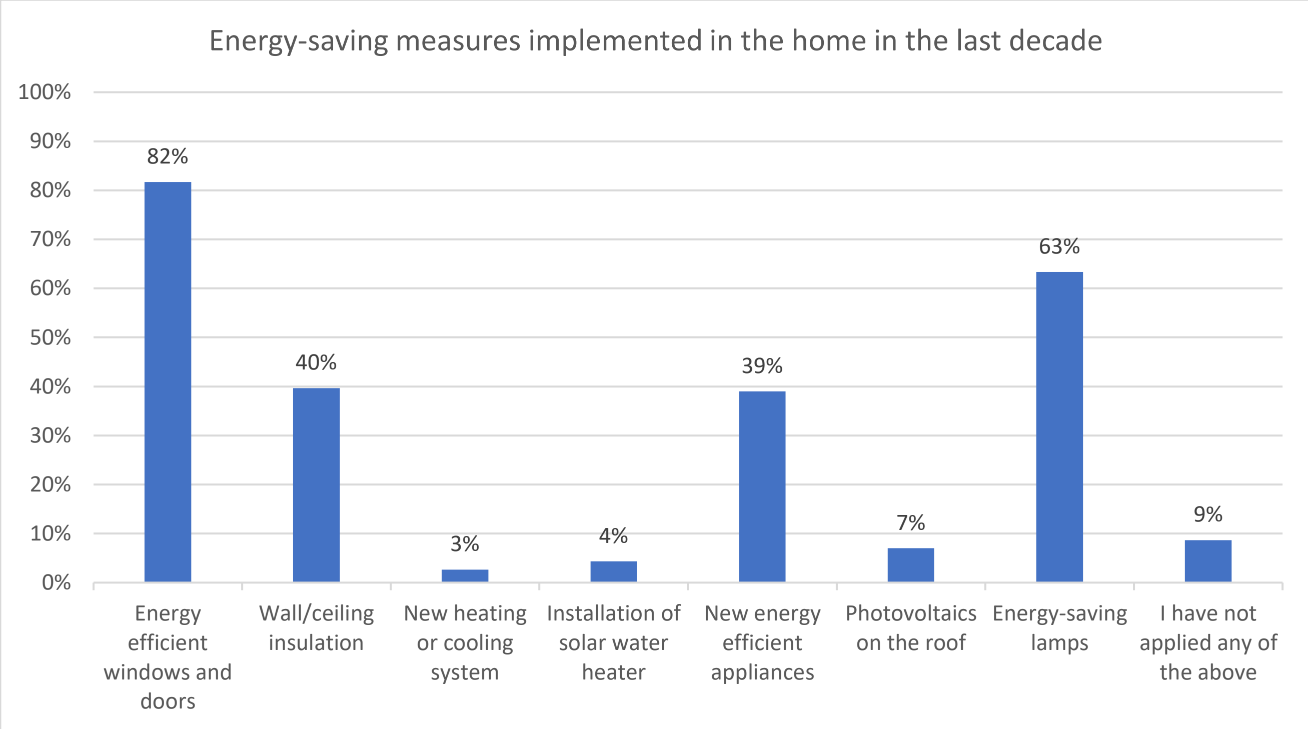


Figure 32. Energy-saving measures implemented in the home in the last decade

It should be noted here that until recently, Brezovo was not priority in the programs for financing energy saving measures, because according to the national program for energy renovation of homes, priority was mainly given to multi-family residential buildings, and single-family houses prevail in Brezovo. Also, the environmental protection program, which relied on the replacement of heating sources with modern low-emission ones, was only for large cities. The program for the introduction of RES in households has only recently been opened, and no real activities for the installation of photovoltaic or solar collectors for hot water can be reported yet.

As expected, Figure 33 shows that 96% of the respondents haven't participated in any subsidy programs for energy efficiency.

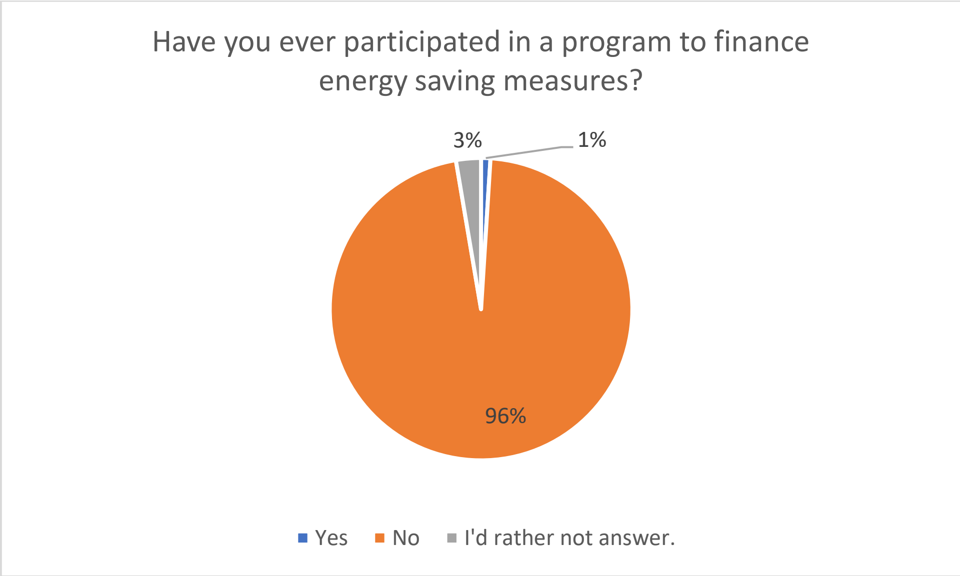


Figure 33. Participation in subsidy programs for EE

Those who had not participated in funding programs, they were asked whether they would participate in the future, 67% answered positively, but a quarter answered that they would not participate (Figure 34).

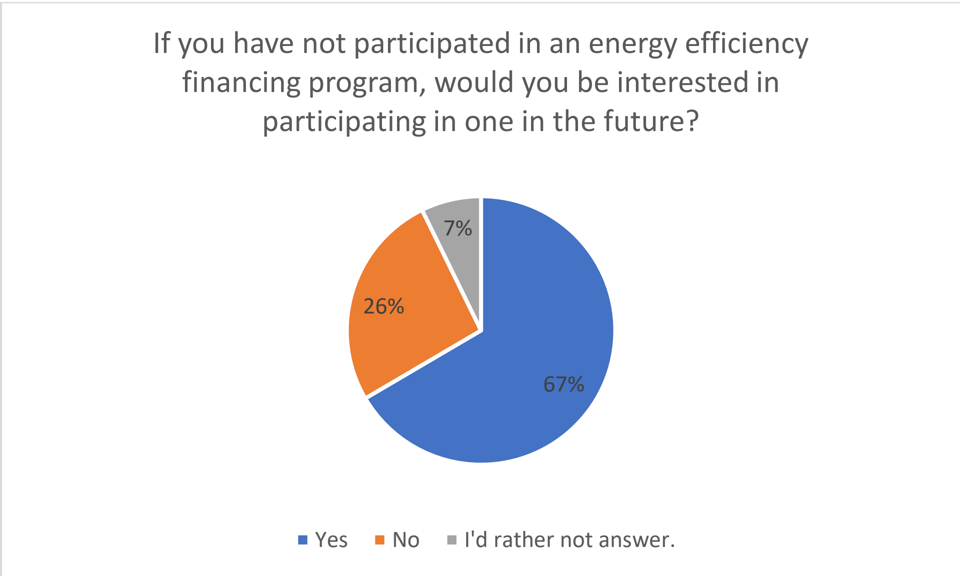


Figure 34. Willingness to participate in energy efficiency programs

Figure 35 shows that more than a half (62%) indicated that they don't know about any programs. This should be one of the key findings of the analysis to focus on raising awareness of funding opportunities. Interesting that no small part - 22% have answered that they don't think that this will reduce their energy costs. This means again that more information campaigns should be focused among the population. It also turns out that the worry of excessive bureaucracy and administrative obstacles in the participation and implementation of energy efficiency measures under financing programs is not a small problem – 19% have answered about this reason.

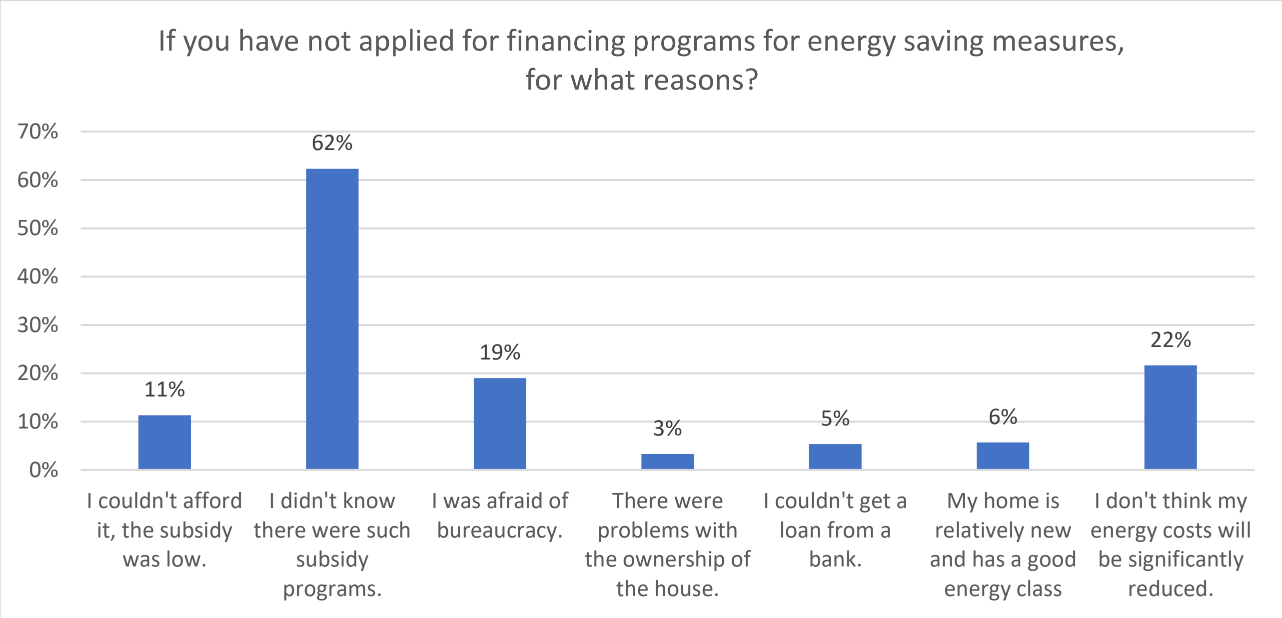


Figure 35. Reasons for not applying for financial programs

When asked about their opinion on state and local support for energy efficiency measures and building renovations, most respondents said they agree that such support is needed (more than 60%) (Figure 36). On the statement that energy suppliers treat low-income consumers fairly, opinions are mixed, with 15% disagreeing and 16% somewhat disagreeing. Also, 32% have indicated that they rather agree and 37% agree with this opinion.

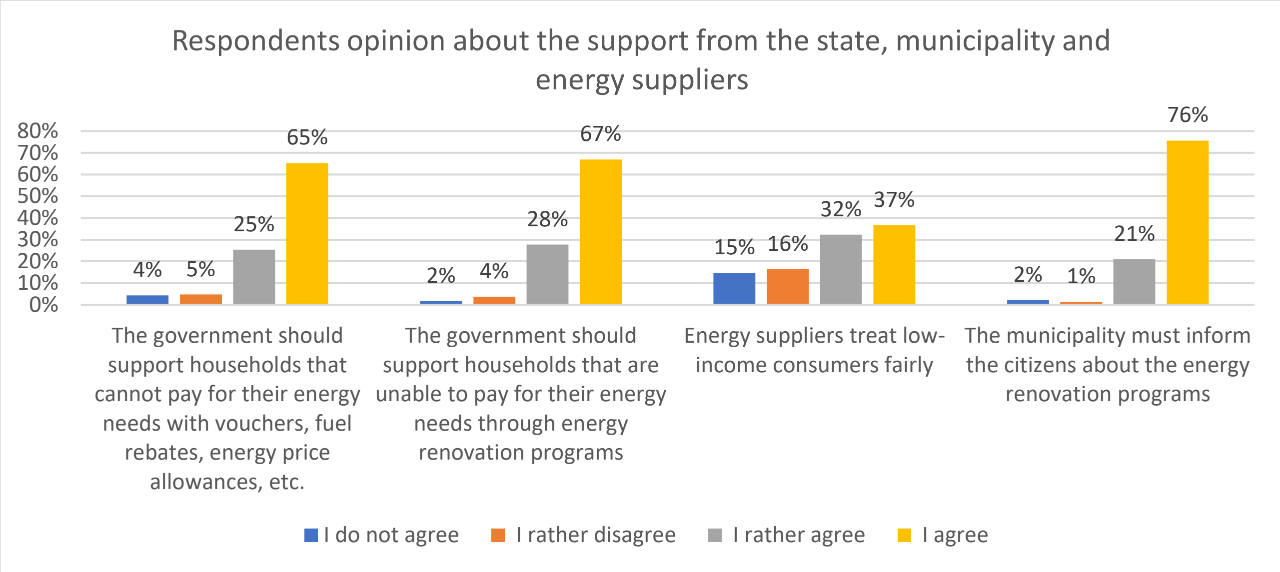


Figure 36. Respondents opinion about the support from the state, municipality and energy suppliers

Finally, when asked if they plan EE measures, and if so, what value they would be willing to pay, 81% have indicated that they don't know (meaning that they are not planning, or don't thinking about energy efficiency in their homes). Only 10% indicated that they are willing to pay less than 100 BGN (or 50 EUR) per month and 5% are willing to pay between 100-200 BGN (50-100 EUR) (Figure 37). This is also a clear sign that emphasis should be placed on raising awareness among citizens, working on their involvement and encouraging them to be involved in EE programs and to be supported in the overall renewal process.

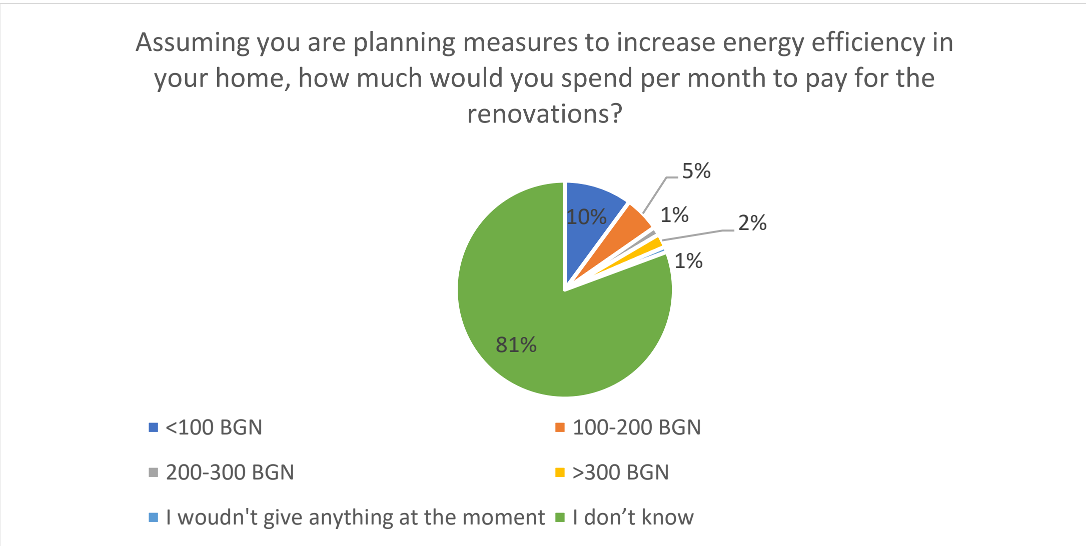


Figure 37. Willingness to pay for renovation

1.7 Energy poverty, vulnerability and behavioural perspectives

Unfortunately, Bulgaria takes the leading places in many of the indicators used by the Energy Poverty Observatory, which is not accidental, since all three main factors that determine the level of energy poverty are present:

(a) low income

(b) high energy prices relative to purchasing power

(c) buildings with unsatisfactory energy performance.

It can be said that Brezovo is a typical representative of a settlement with a strong level of energy poverty as a rural town, with a high level of unemployment and an aging population.

When the energy performance of the dwelling is poor and more energy is needed for heating, household income is insufficient and the cost of energy is relatively high relative to income, it is difficult to provide "*adequate heating*" according to the definition presented above. In this case, *households are deprived of part of their necessary energy and live in a degraded state comfort.* Unfortunately, this indicator is difficult to measure with objective data and relies primarily on consumer self-reports obtained through sample surveys. The same is the case with the other indicator monitored by the Energy Poverty Observatory: whether households can pay their energy consumption on time. In this case, the following hypothesis is considered: "*Energy poor are those households that cannot pay on time their heating bills and have accumulated energy liabilities.*"

The following graphs show to what extent the residents of Brezovo are affected by the indicated characteristics of energy poverty.

Figure 38 shows that 17% of the respondents are unable to keep home adequately warm in the winter or cool in the summer. 16% have condensation on windows and walls during winter. There are only 2% indicated arrears in the energy bills over the last 12 months and only 1% stated that have electricity or heating suspension due to non-payment of the bills.

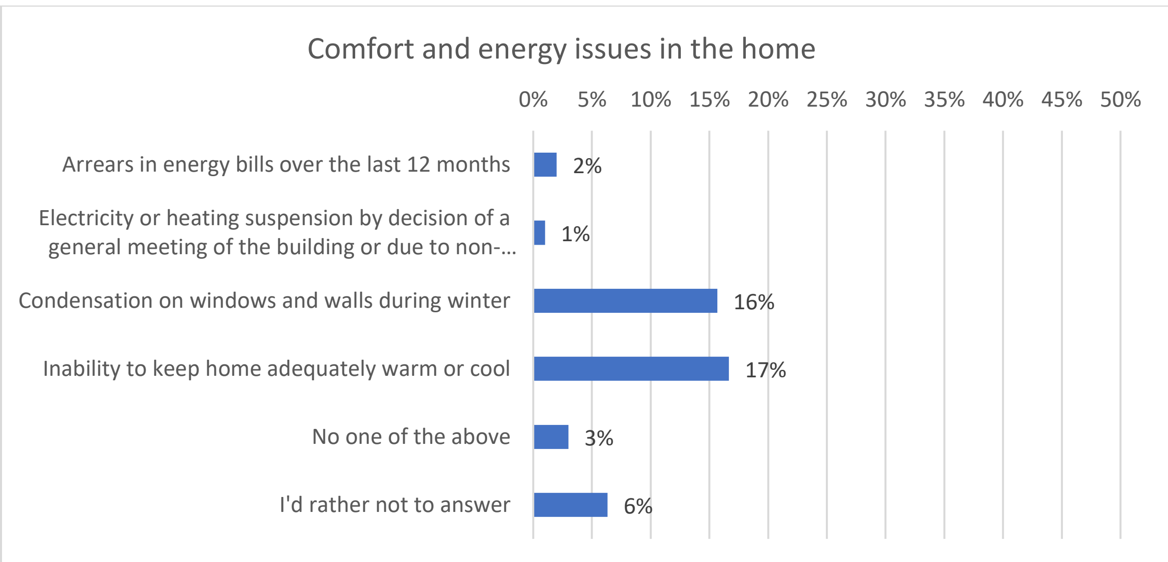


Figure 38. Comfort and energy issues in the home

On the other hand, it is common to restrict other necessary products or services or basic needs in order to be able to pay energy bills. Most often, respondents reported reduced use of electrical appliances and lighting – 16%. Furthermore, 12% report cut back on entertainment, and another 12% report cut back on clothes, shoes, etc. Finally, 10% indicated cut back on food purchases. The smallest part (5%) of the households is deprived of medicines.

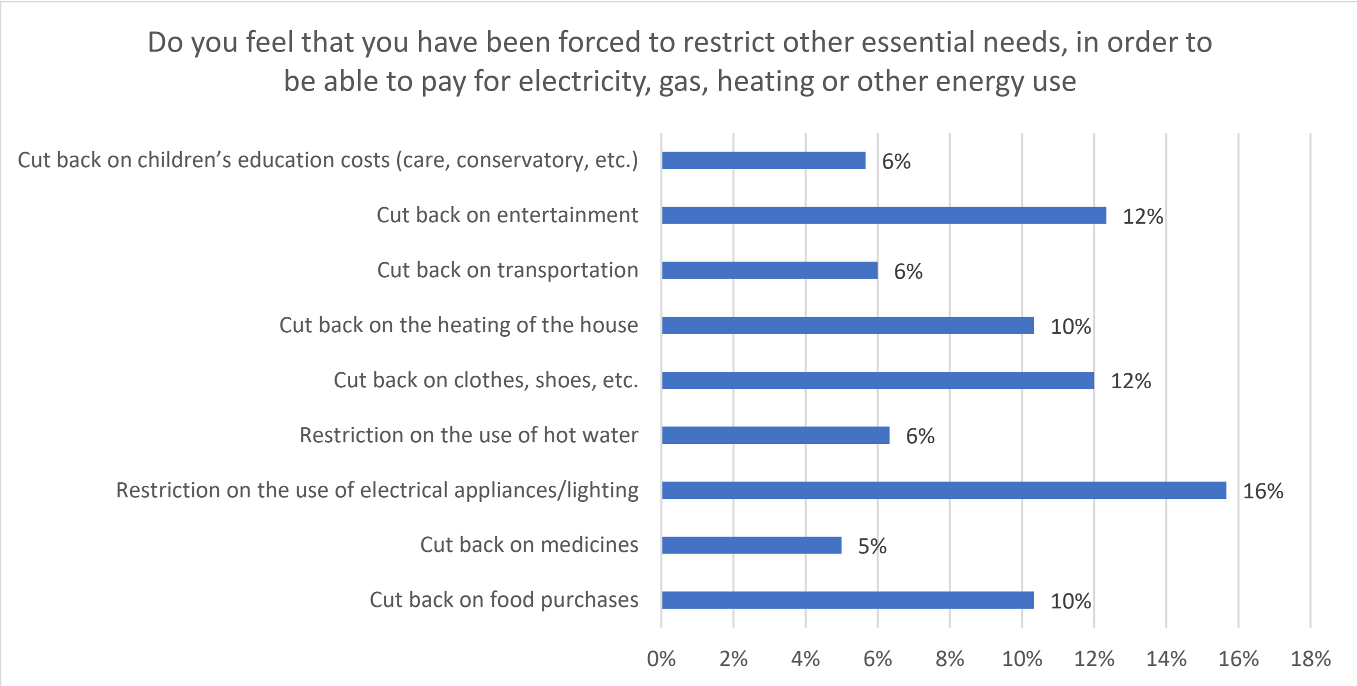


Figure 39. Restrictions of other essential needs in order to pay for energy, over the last 12 months

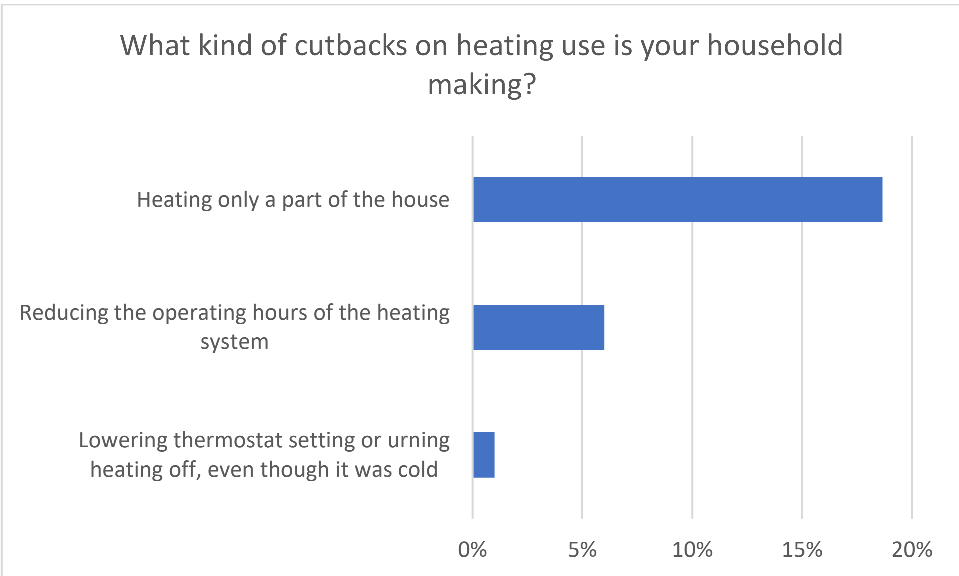


Figure 40. Heating cutbacks on heating use

2 Pilot 2 - Athens Urban area (Greece)

2.1 Survey administration

Information was collected between May 25th and June 30th, 2023 via an online surveying platform (LimeSurvey). The target group was households residing in Athens Urban Area (also known as Greater Athens), and only individuals 18 years of age or older could participate in the survey. The survey was communicated through two different channels:

(a) through an email sent to the list of EKPIZO members living in the area of interest (approximately 2,700 people) and

(b) through the website and social networks of EKPIZO, municipalities and other organisations (external collaborators, journalists, consumer associations, etc.) who participate in the project efforts.

In total, 754 people followed the survey link they received from either a personal email or were informed via websites and social networks, and 496 people finished the survey.

Although the questionnaires collected exceeded the initial target by 65%, some issues that may have affected the survey should be noted. The main drawback of this mode of administration is that some EKPIZO members who received the invitation might disregard the survey email due to the overwhelming number of emails they receive. Also, some EKPIZO members may have deactivated their email addresses or stopped checking them regularly. Furthermore, not all members of the population of interest have internet access, and some may face difficulties due to internet illiteracy (Duda & Nobile, 2010). Consequently, these groups could be underrepresented in the survey results, affecting the ability to draw a random sample (Andrade, 2020; Daikeler et al., 2020). Finally, to prevent participant attrition and incomplete responses, the survey's length was specified upfront and was kept less than 15 minutes.

2.2 Demographics

As mentioned, a total of 496 households participated in the socioeconomic survey with complete information. The main demographic characteristics are presented in Table 2 and are summarised below.

About 54% of the respondents were female and 46% were male. The majority of the respondents (33.7%) were between 50 and 59 years old, 24.2% were between 40 and 49 years old, 21.6% were between 60 and 99 years old, and 11.7% were between 30 and 39 years old. Also, 6.5% were more than 70 years old and 2.0% were between 18 and 29 years old, i.e., younger households are underrepresented in the sample.

As far as the educational level is concerned, about three-fourths of the participants (75.4%) had access to tertiary education. About 1.4% have not reached high school, about 14% have stopped their education at the end of senior high school or followed secondary vocational education, and 7.5% have finished a 2-year post-secondary vocational degree.

Most of the households (about 32%) include two persons, 23% three persons, 26% four or more persons, and 18.3% of them consist of single-person households. Furthermore, about 10% of the households have children less than 5 years old and 35% have students. On the opposite side, about 37% of the households have at least one resident who is retired. Finally, about one-fifth of the households who participated in the survey have at least one household member of any age with a disability or long-term illness.

Regarding employment status, more than 70% of the households have at least one member who works on a regular, full-time, basis (about 31.5% have more two members or more), while 16.3% have at least one member in long-term unemployment.

Table 2. Sample demographics – Athens Urban Area

Gender	Female	53.6
	Male	45.8
	Prefer not to answer	.6
Age class	18-29	2.0
	30-39	11.7
	40-49	24.2
	50-59	33.7
	60-69	21.6
	>70	6.5
	Prefer not to answer	0.2
Household members	1	18.3
	2	31.9
	3	23.0
	4	20.8
	5	3.6
	6	.6
	More than 6	.2
	Prefer not to answer	1.6
HH with children less than 5 years old	1	6.0
	2 or more	4.2
HH with students	1	16.5
	2	16.7
	3	1.6
	More than 3	.4
HH with pensioners	1	26.6
	2	10.5
	More than 2	.2
Full-time employed HH members	1	39.7
	2	31.3
	3	1.4
	More than 3	.2
Long-term unemployed HH members	1	15.1
	2	1.2
HH members with disabilities/long-term illness	1	19.8
	2	2.0
	3	.2
Educational level	Incomplete primary school	.2
	Primary school	1.2
	Secondary school	8.3
	Secondary vocational education	5.6
	Post-secondary vocational education	7.5
	Tertiary education	75.4
	Prefer not to answer	1.6

Focusing on household economic status-related aspects, the average net monthly income of the households (including allowances, rental income, etc.) is €1,825 (s.d.=€917) (Table 3) and the average total household expenditure per month for all items (including food/clothing/rent/loans/ entertainment/ transportation, etc.) is €1,430 (s.d.=€693) (Table 4).

Table 3. Net monthly income of all household members

Net monthly income	Percentage
Up to 250 €	2.0
251 – 520 €	1.0
521 – 680 €	2.4
681 – 850 €	5.4
851 – 1,000 €	7.1
1,001 – 1,250 €	8.9
1,251 – 1,500 €	11.3
1,501 – 1,950 €	14.5
1,951 – 2,500€	14.3
2,501€ – 3,300€	7.3
More than 3,301 €	11.3
Prefer not to answer	14.5

Table 4. Total monthly household expenditure

Total monthly household expenditure	Percentage
Up to 250 €	1.0
251 – 520 €	5.5
521 – 680 €	5.5
681 – 850 €	8.1
851 – 1,000 €	8.5
1,001 – 1,250 €	9.9
1,251 – 1,500 €	12.7
1,501 – 1,750 €	7.9
1,751 – 2,000 €	11.1
2,001 – 2,500 €	8.5
More than 2,501 €	8.3
Prefer not to answer	13.1

On average, the ratio of total expenditure to net income is 86.8% (s.d.=41.1%). As shown in Table 5, more than 50% of the households claim that they spend more than 70% of their available income to cover their expenditure needs.

Table 5. Total expenditure to net income ratio

Expenditure to net income ratio	Percentage
Less than 30%	3.2
30%-50%	6.7
50%-70%	15.7
70%-85%	15.1
85%-100%	30.7
Over 100%	5.4
No response	23.2

About 5% claim that they spend more than 100% of their income. Although the possibility of dishonest answers cannot be ruled out, especially to the income question, all these households say that they find it difficult to survive on their income. Similar results have been observed in other studies. For example, in a recent survey of IME GSEVEE, a non-profit organisation that carries out studies and surveys, acting as GSEVEE's (the Hellenic Confederation of Professionals, Craftsmen, and Merchants) scientific advisor, more than half of households said their monthly income is only enough for 18 days due to soaring energy and food prices[1]. In total, 47.5% of the households are struggling to cope with current income, 33.1% are able to make ends meet on current income, and 10.5% live comfortably. Moreover, about 9% refused to answer this question.

As shown in Figure 41, all households with a net income below €680 say they are struggling to make ends meet. About 75-80% of the households with an income between €680 and €1,250 say that they find it difficult to make ends meet. This percentage decreases to 50-60% for households with an income between €1,251 and €1,950 and further to about 30% for those with a net income between €1,951 and €2,500. Finally, households with a net income above €2,500 experience difficulties to a much lesser extent (10% or less).

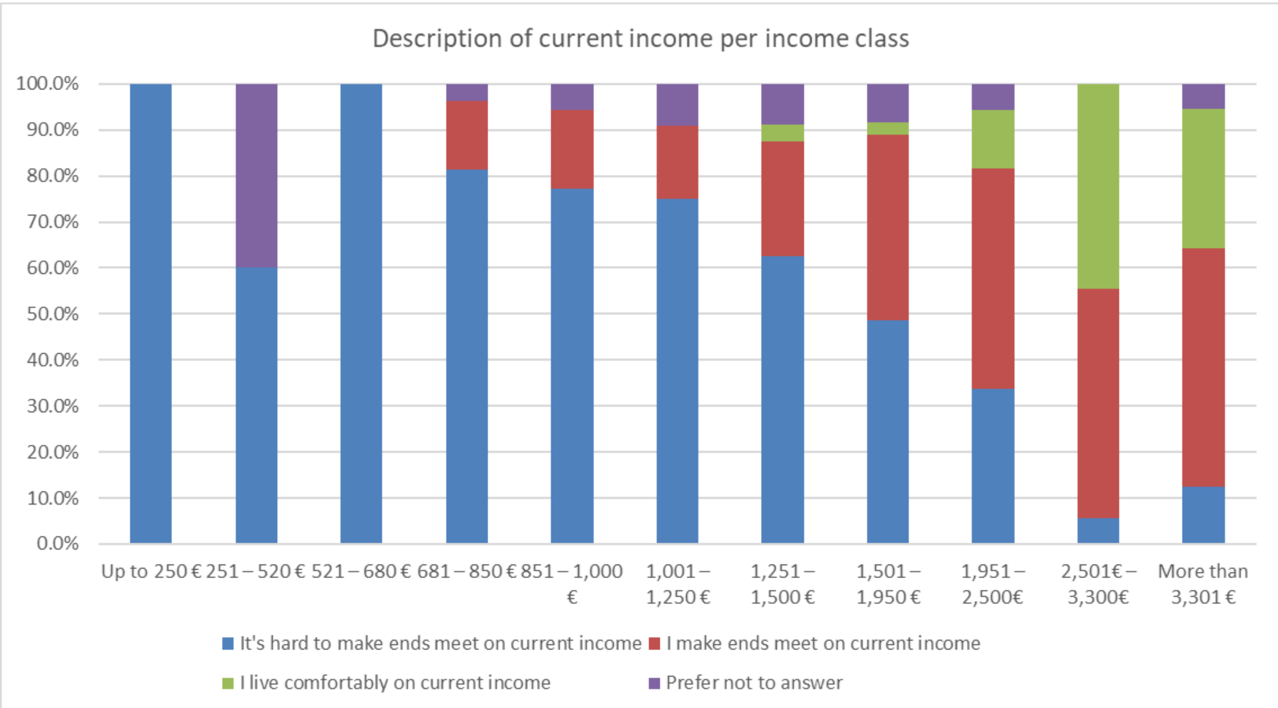


Figure 41. Description of current income per income class

As shown in Figure 42, the presence of young children (less than 5 years old) or pensioners in the household does not lead to high rates of inability to meet needs (the percentage is practically the same as those of households without young children or pensioners). However, differences are found in households with disabled or long-term unemployed persons. These households have

[1] https://imegsevee.gr/wp-content/uploads/2022/03/eisodima-2022.pdf

generally lower incomes. Therefore, it seems that household income seems to be the most decisive factor in meeting needs.

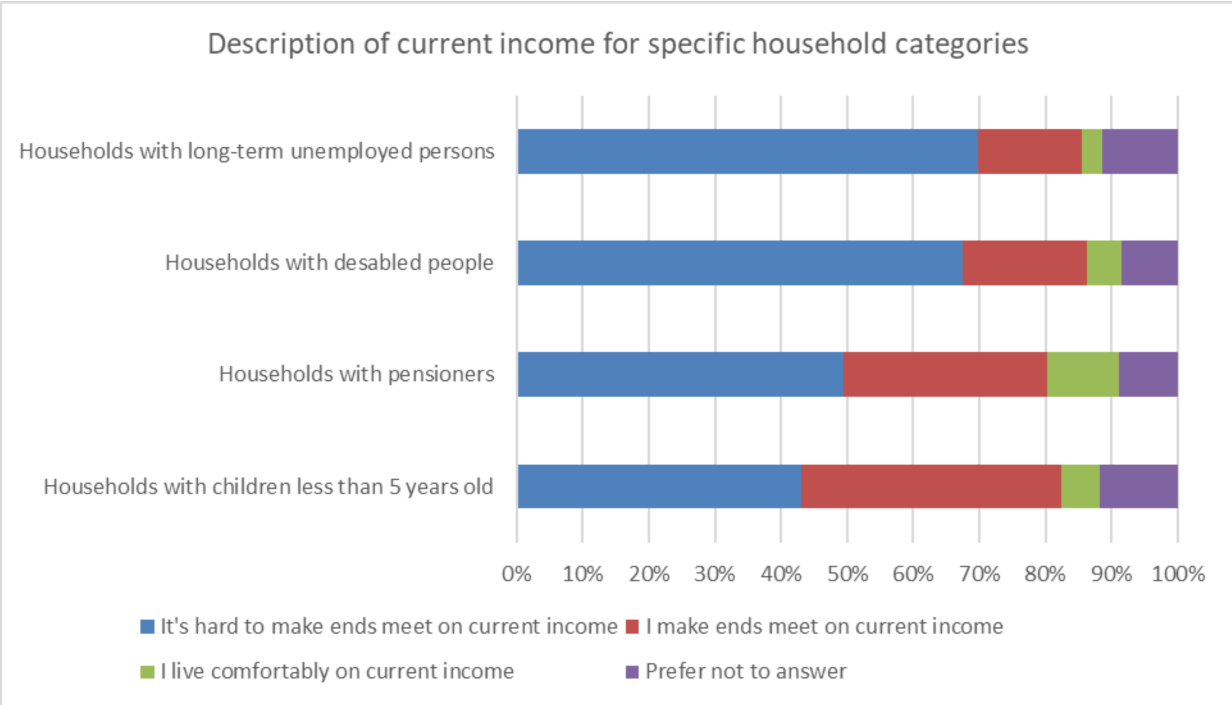


Figure 42. Description of current income for specific household characteristics

2.3 Housing characteristics

As expected, about 80% of residences are apartments, 19% are detached houses, and the rest are maisonettes. Most of the apartments (37.7%) are on an intermediate floor of the building, followed by apartments located on the top floor of the building (22.8%) and the first floor (10.3%).

As shown in Figure 43, about 40% of the dwellings were constructed before 1980. These buildings lack basic insulation standards as the first Insulation Regulation in Greece was practically implemented in 1980. Further, 22.6% were built between 1981 and 1995, 23.4% were built between 1996 and 2005 and the rest after 2006.

Regarding the total floor area, 11.5% of the residences are less than 60 m^2, 19.6% are between 60-80 m^2, 35% are between 80-100 m^2, 14.9% are between 100-120 m^2, and the rest are over 120 m^2 (Figure 44). Further, nearly 17% have two rooms or less, 31% have three rooms, 31.5% have four rooms, and the rest have five or more rooms, except bathrooms and storage rooms (Figure 45).

Finally, as shown in Figure 46, most dwellings (i.e., 39.5%) are privately owned without financial obligations, followed by privately owned with financial obligations (loan, mortgage, etc.) (31.9%) and rental houses owned by an individual (22.6%). Also, a small percentage of dwellings have been provided free of charge by family, friends, employers, or other.

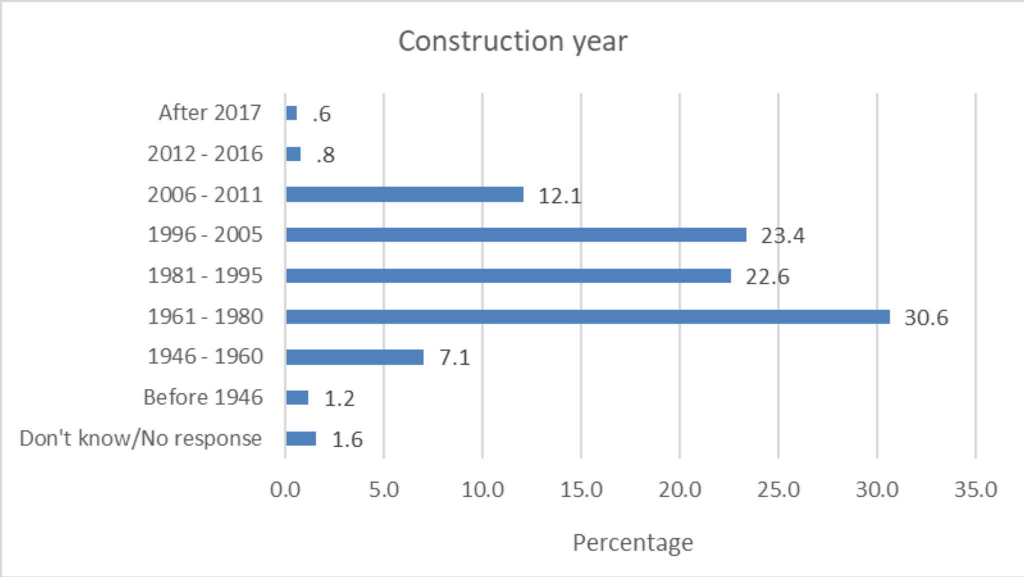


Figure 43. Construction year of dwellings

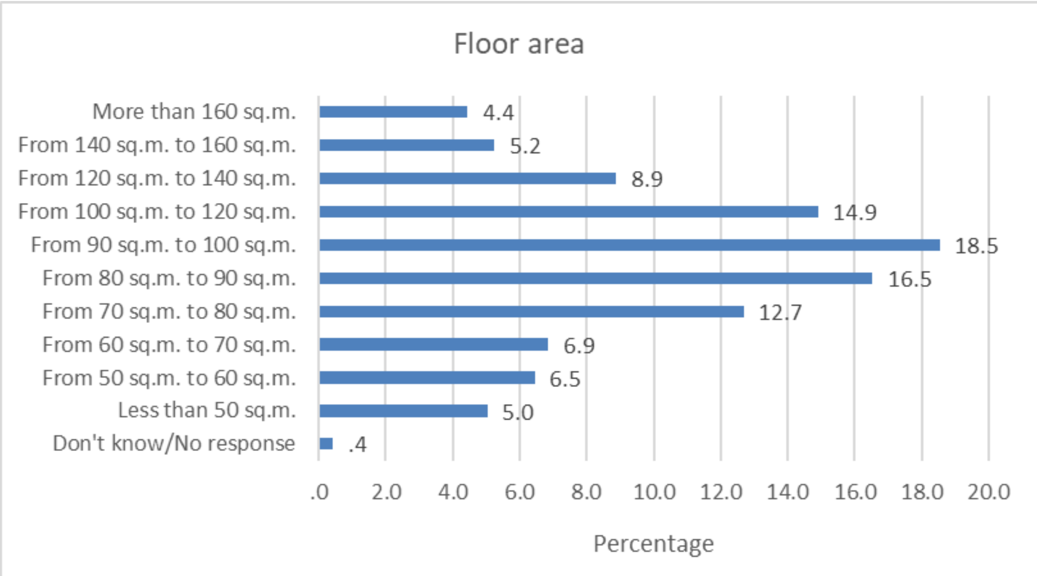


Figure 44. Distribution of dwellings by size

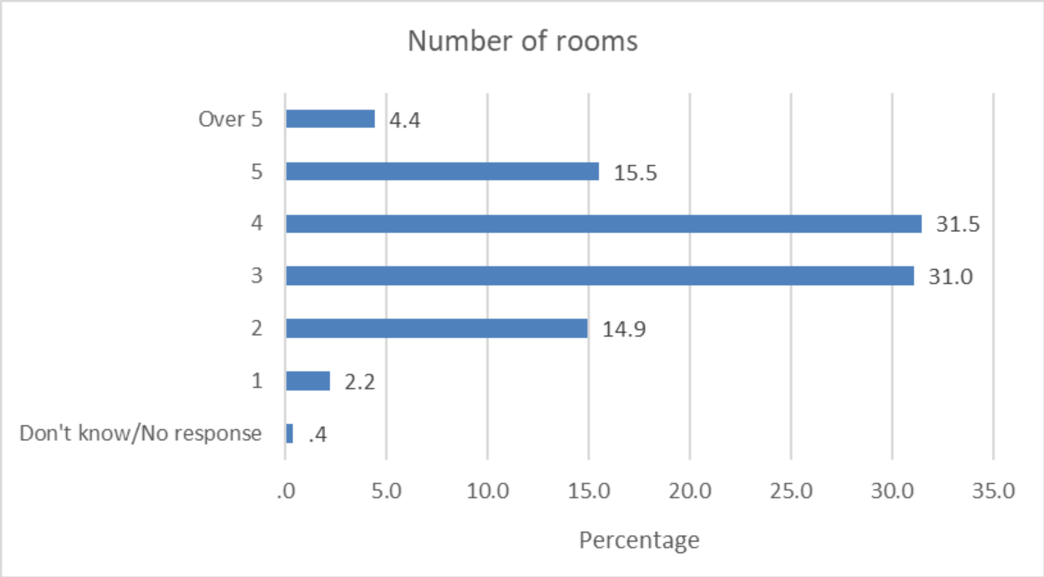


Figure 45. Distribution of dwellings by number of rooms (other than bathrooms and storage areas)

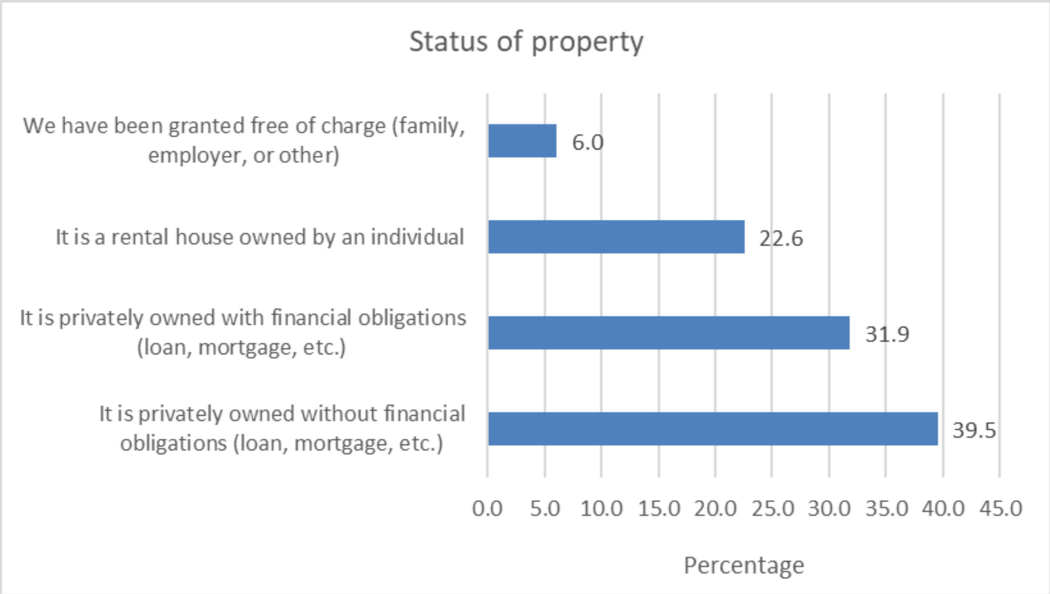


Figure 46. Status of property

2.4 Mechanical systems

As illustrated in Figure 47, 56% of the households that took place in the survey heat their homes using central heating systems, dominated by heating oil (41.1%) and natural gas (14.5%). The rest of the households use other systems, mainly air-conditioning units (13.9%), individual heating with natural gas (12.3%, and electrical devices (4.6%). Due to the urban character of the pilot area, other options, such as firewood/pellet stoves and fireplaces are less popular. The same applies to some energy-efficient heating devices, such as heat pumps. This finding is important as it indicates that there is considerable scope for upgrading existing heating systems. Finally, it is also important to note that about 2.5% of the participants state that they do not heat their homes at all.

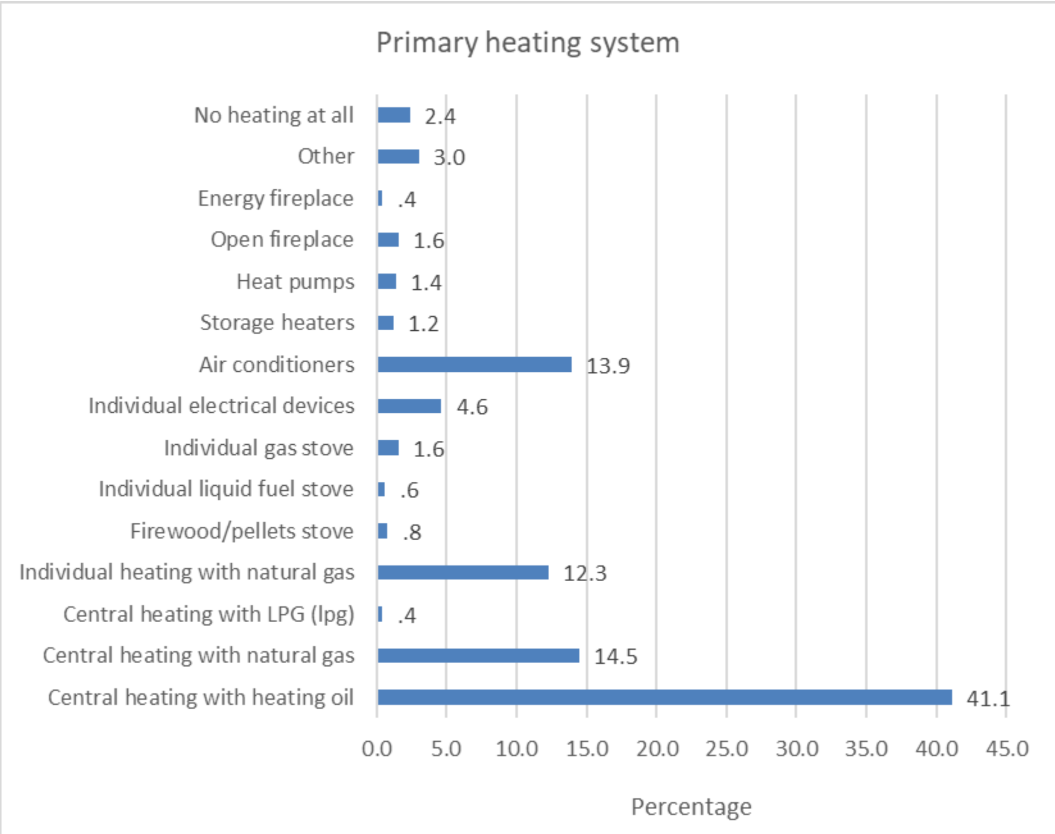


Figure 47. Primary heating system

Following Figure 48, It is interesting to note that 9 out of 10 of those who have central heating with heating oil and 8 out of 10 of those who have central heating with natural gas are also using supplementary heating systems, mainly air conditioners (51.4% and 59.6%, respectively), open fireplace (24.6% and 15.8%, respectively), and electrical devices (15.3% and 22.8%, respectively). Since these systems are used to heat the total surface area of a dwelling, this finding suggests a reduction in the hours of operation of the central heating system due to high energy costs, either by collective decision (in many old multi-family buildings the heating system operates centrally, without the possibility of autonomous operation per apartment) or by individual decision. The same observation applies to other heating systems, but this is to be expected, as these systems basically heat only one part of the house. Obviously, this is not the case for heat pumps, storage heaters and central heating with LPG but as they constitute a very small proportion of the sample no conclusions can be drawn.

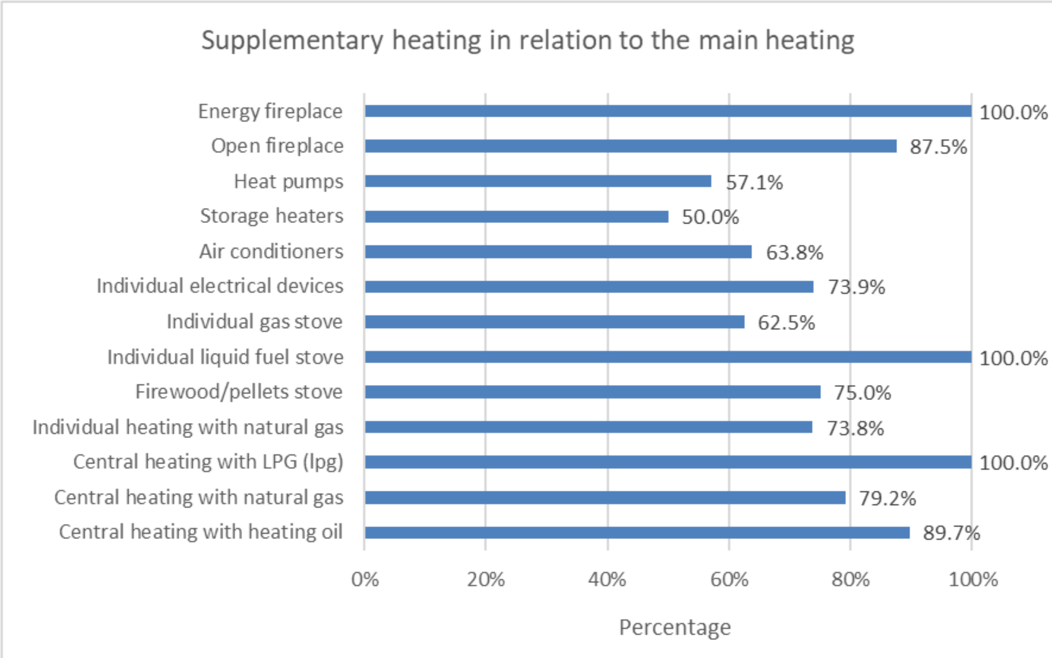


Figure 48. Supplementary heating in relation to the main heating system

Furthermore, according to the following figure (Figure 49), those who are struggling to make ends meet rely mainly on individual firewood/pellet and gas stoves, air conditioners, and open fireplaces. That is, they most probably heat only part of their homes and use (as far as the open fireplaces and firewood/pellet stoves are concerned) heating systems that degrade indoor air quality.

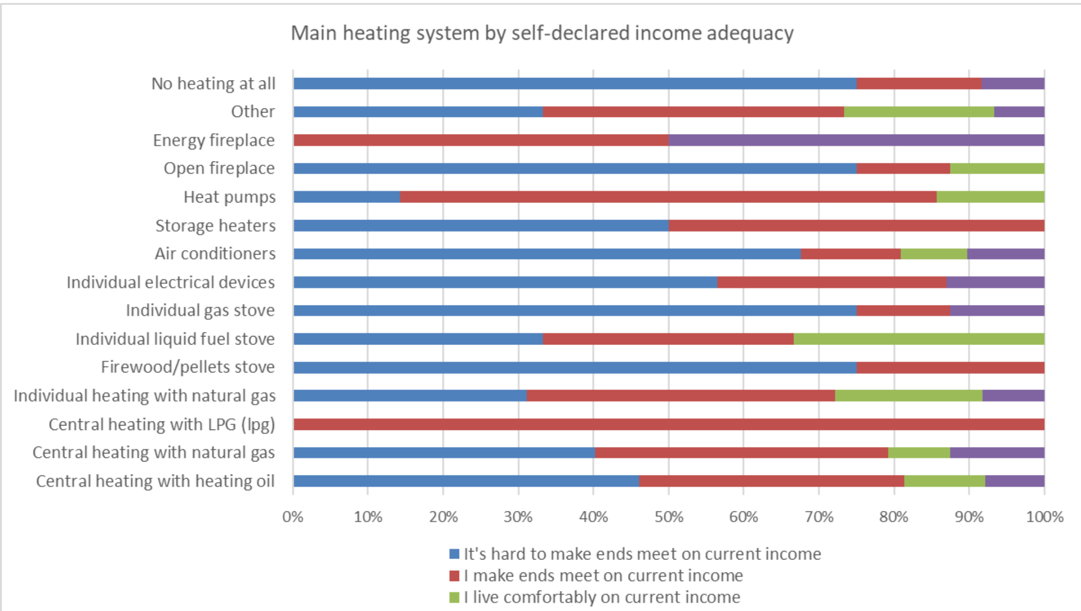


Figure 49. Main heating system by self-declared income adequacy

As far as cooling is concerned, air conditioning units are used in residential buildings at a rate close to 100%, and for this reason cooling systems were not examined in more detail.

Households produce hot water mainly from solar water heaters (52.8%) and electric water heaters (46.2%), either exclusively or in combination with other systems (Figure 50). In more detail, 36.5% of the households use only solar water heaters, 32.5% use only electric water heaters, 9.3% use only boilers and 0.8% use only instantaneous water heaters. The remaining households use combinations of the above systems, the most popular of which are electric/solar water heaters (7.3%) and solar water heater/boiler (5.8%).

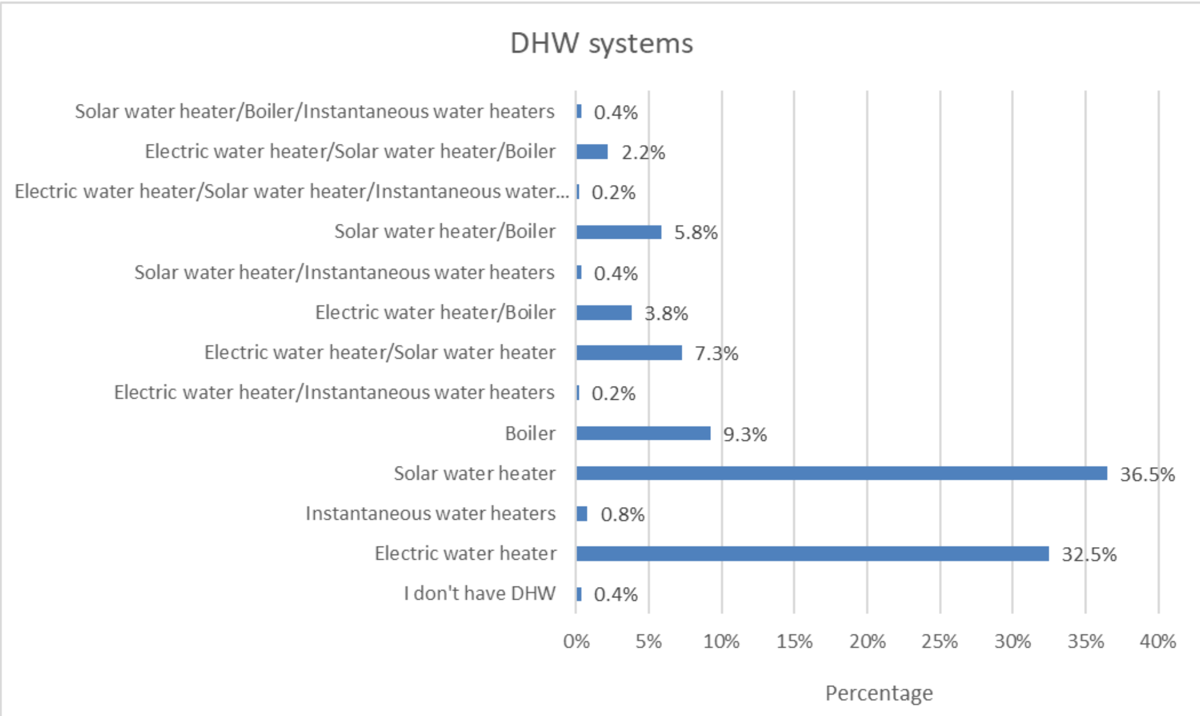


Figure 50. DHW systems

As shown in Figure 51, most vulnerable households rely mainly on electric water heaters and instantaneous water heaters and less on boilers, solar water heaters or other combinations.

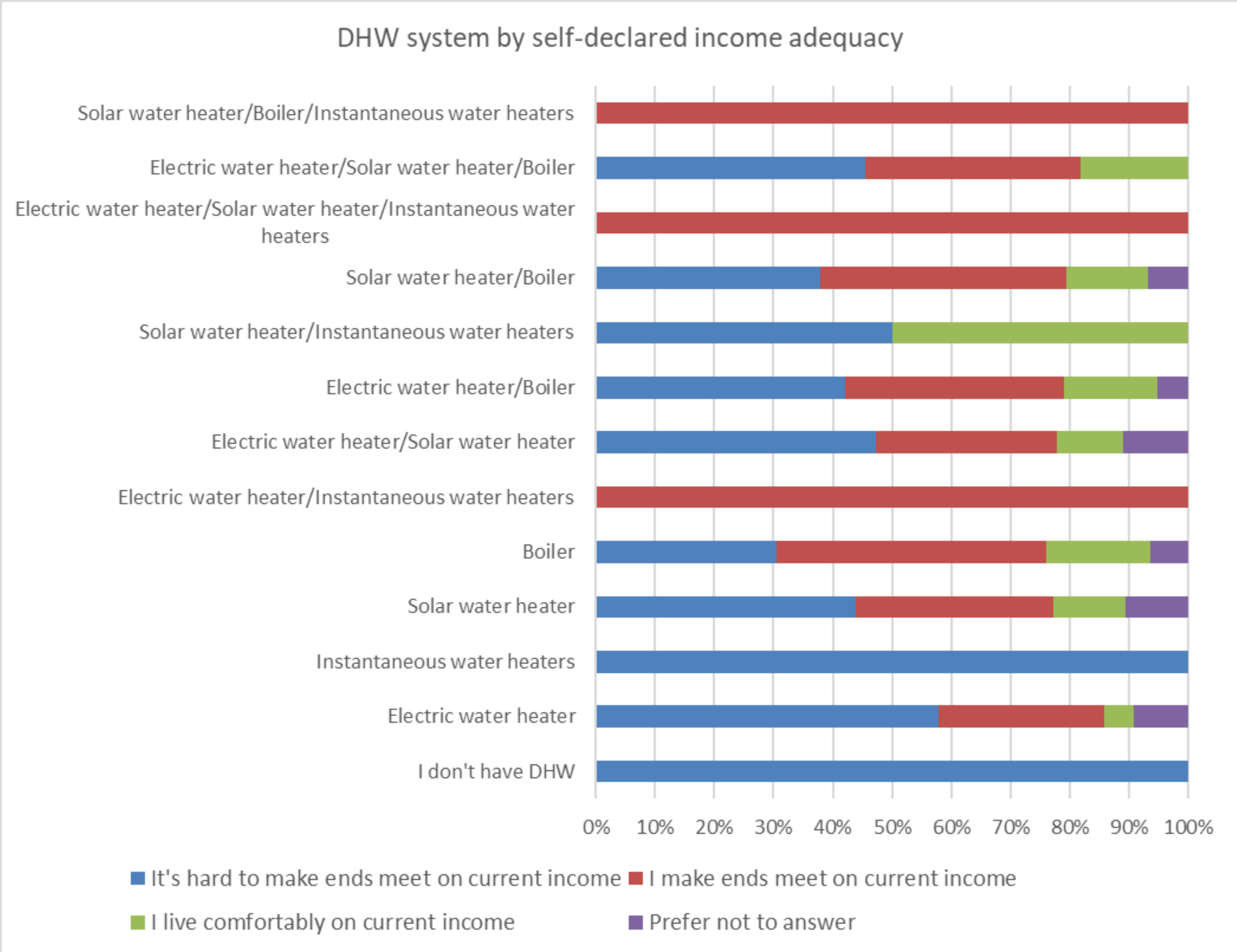


Figure 51. DHW system by self-declared income adequacy

2.5 Energy costs and habits

2.5.1 Heating/cooling awareness and behavioural issues

As shown in Figure 52, most of the households (about 35%) operate their heating system between 2 and 4 hours per day and about 20% between 4 and 6 hours per day. Another 20% operate their heating system for less than 2 hours per day or not at all. On the opposite site, about 8% say that they turn on the heating system for 6 to 10 hours per day or more. It is noted that around 13% of the participants mentioned that they keep the heating on constantly using a setback temperature. If the setback temperature is right, the heating will be off for a normal amount of time and can help avoid energy wastage because most people turn the thermostat up higher than normal comfort level when they return to a cold house. Nevertheless, if the house is not energy efficient, any heat generated is lost fairly quickly and, thus, it will be more cost effective to turn on the heating system when needed.

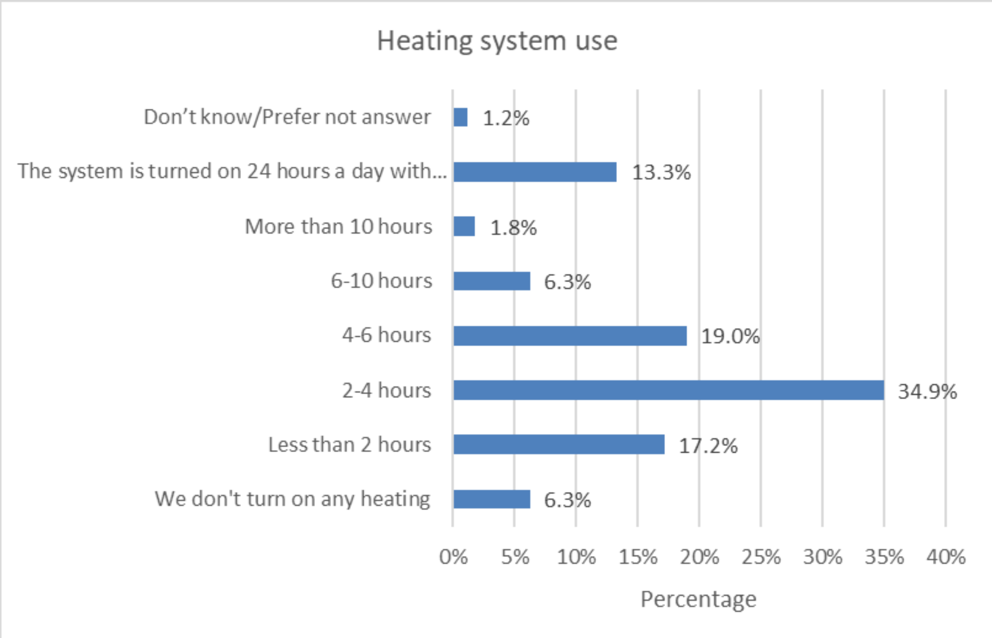


Figure 52. Operating hours of heating system

About two-thirds of the participants said that the ideal indoor temperature is between 18-21°C (Figure 53). This temperature range is indeed ideal and recommended by international bodies, such as the World Health Organisation (WHO), and by energy experts. Furthermore, about 30% believe that the ideal indoor temperature during the winter months is above 21°C. Setting the wrong temperature on the thermostat would overheat the house, leading to wasted energy and excessive energy expenditure.

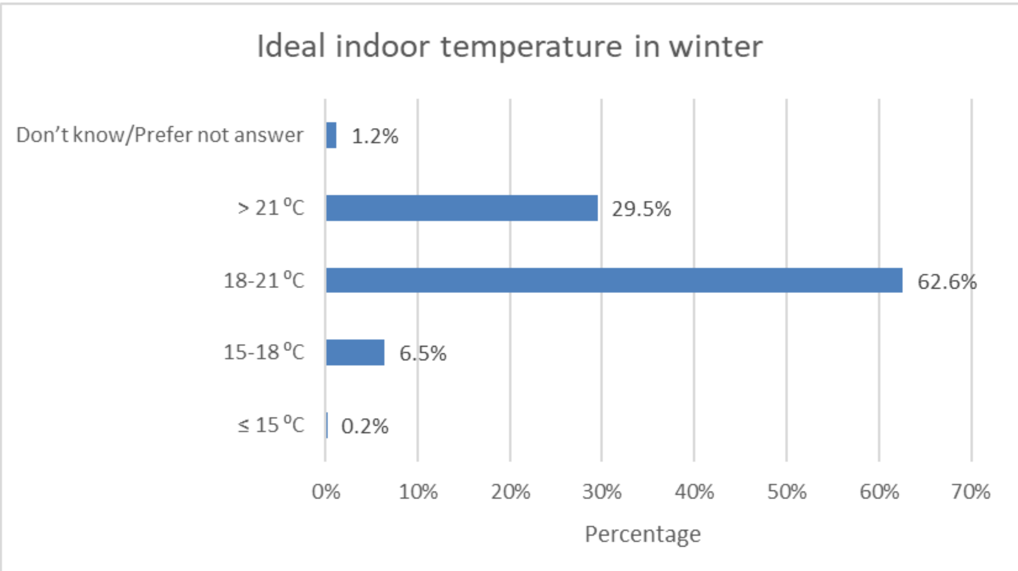


Figure 53. Self-perceived ideal indoor temperature

However, according to Figure 54, only 5% of households in the survey can heat their home to a temperature above 21ºC, and 39% to the ideal temperature of 18-21ºC. More than half of the households report indoor temperature below the room temperature recommended by the WHO.

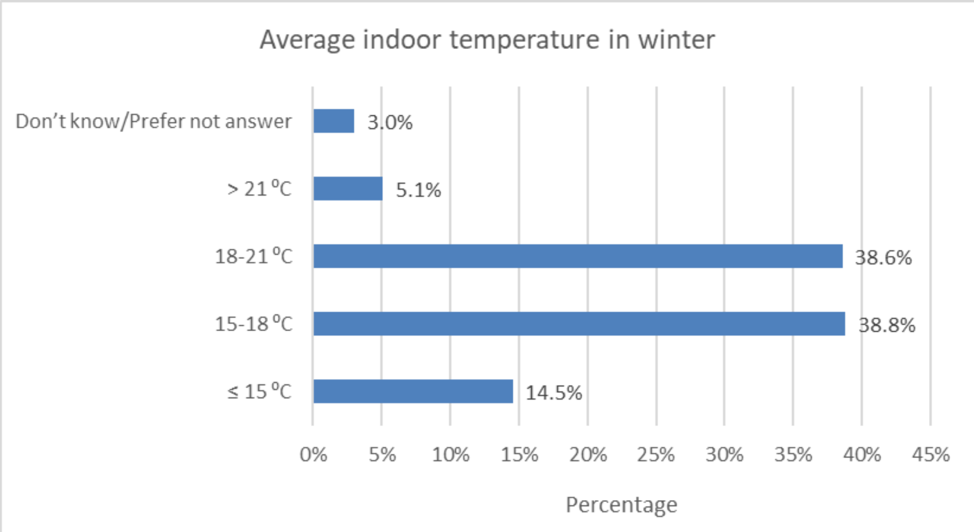


Figure 54. Average indoor temperature

This finding is worrisome. As shown in Figure 55, the percentage of households reporting health problems due to insufficient heating for a house temperature of 15-18ºC is twice as high as the corresponding percentage for a house temperature of 18-21ºC, while the percentage for a house temperature below 15ºC is about four times higher.

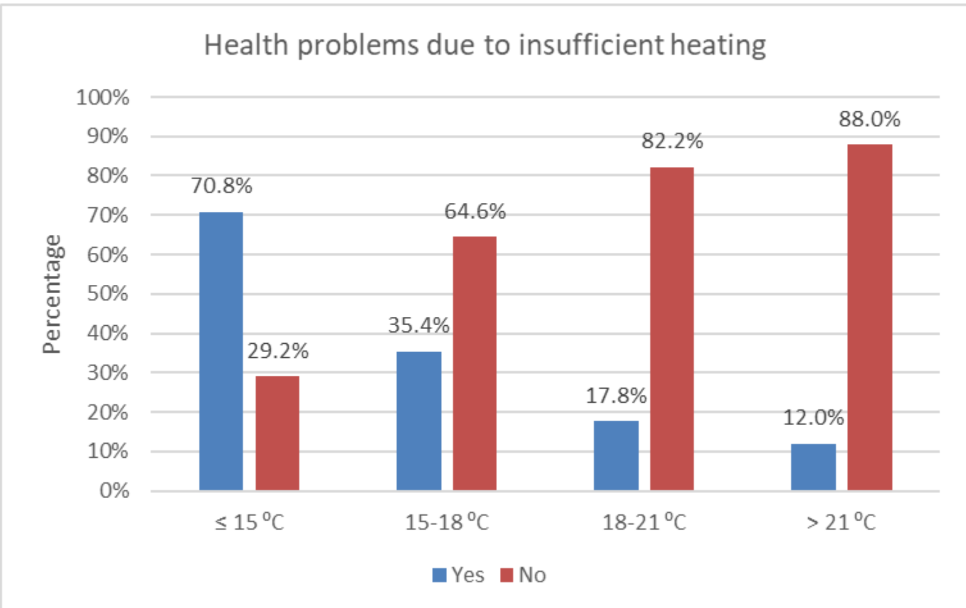


Figure 55. Health problems due to insufficient heating in relation to home temperature

2.5.2 Electricity awareness and behavioural issues

Table 6 summarises the survey responses around electricity-related awareness and behavioural issues.

Table 6. Electricity-related awareness and behavioural issues

I often check the electricity meter reading	Yes	42.8%
	No	55.4%
	Prefer not to answer	1.8%
I compare electricity consumption with previous years	Yes	71.5%
	No	27.3%
	Prefer not to answer	1.2%
I read the consumption (kWh) in the electricity bill	Yes	83.0%
	No	16.6%
	Prefer not to answer	0.4%
I understand the charges on the electricity bill	Yes	44.8%
	No	51.1%
	Prefer not to answer	4.0%
I read the information material that comes with your electricity bill from the electricity supplier	Yes	67.7%
	No	30.1%
	Prefer not to answer	2.2%
I read the information material that comes with your electricity bill from other entities (e.g. consumer associations)	Yes	69.9%
	No	27.7%
	Prefer not to answer	2.4%
I follow the energy-saving instructions given by the electricity supplier	Yes	74.9%
	No	17.8%
	Prefer not to answer	7.3%
I have a digital meter installed and I am regularly informed about my consumption	Yes	4.6%
	No	91.3%
	Prefer not to answer	4.0%
I use the Residential Night Tariff	Yes	62.6%
	No	33.9%
	Prefer not to answer	3.4%

A general conclusion drawn from the answers to the questions posed is the increased interest in information due to the high electricity prices in the last year. The majority of participants (around 70% and even higher) said that they compare the electricity consumption with that of previous years, read the electricity consumption (i.e., kWh consumed) in the electricity bill, as well as the information material that comes with your electricity bill from the electricity suppliers or other entities (e.g., consumer associations). More importantly, three-quarters of them mentioned that they follow the energy-saving instructions included in information materials, and two-thirds make use of the Residential Night Tariff.

On the other hand, knowledge and technical barriers are emerging. More than half of respondents do not check the electricity meter reading on a regular basis, and do not understand the charges on the electricity bill. In the same direction, only 5% have a digital meter installed and are regularly informed about their electricity consumption.

2.5.3 Energy costs

The survey included a number of questions related to households' energy expenditure. The responses are illustrated in the following figures (Figure 56 to Figure 60) and discussed below.

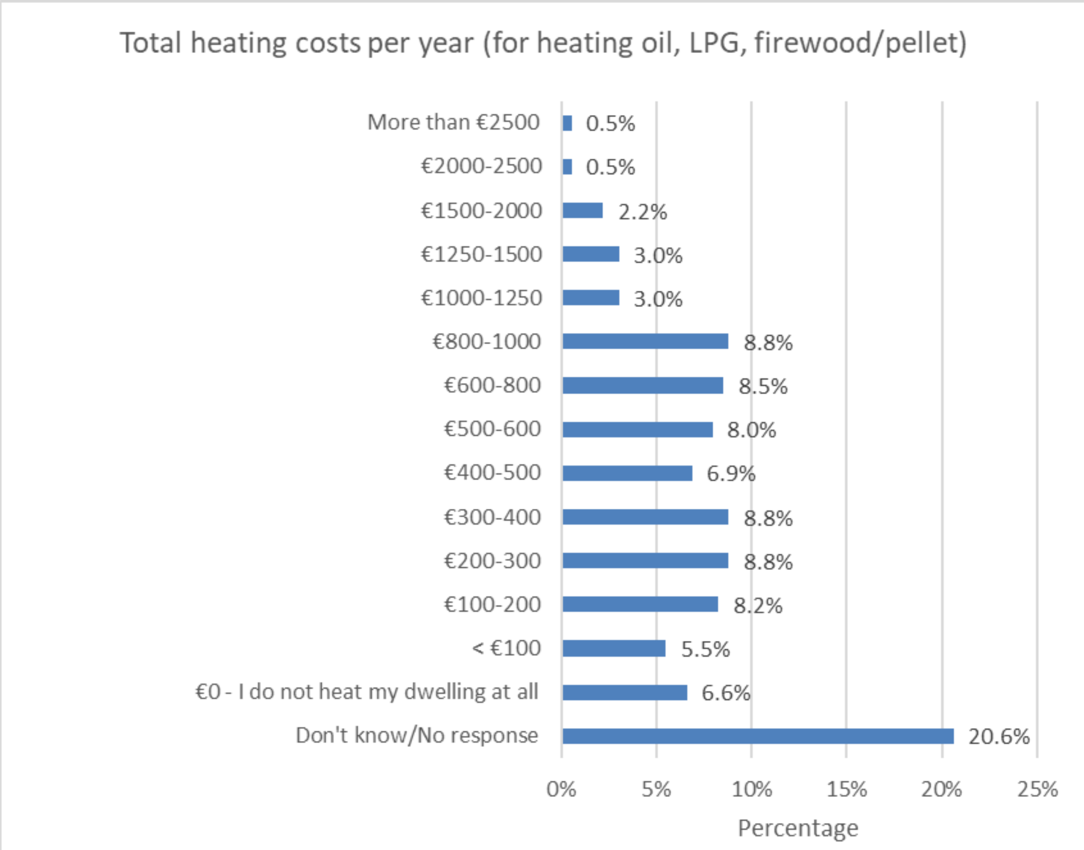


Figure 56. Total heating costs per year (for heating oil, LPG, firewood/pellet)

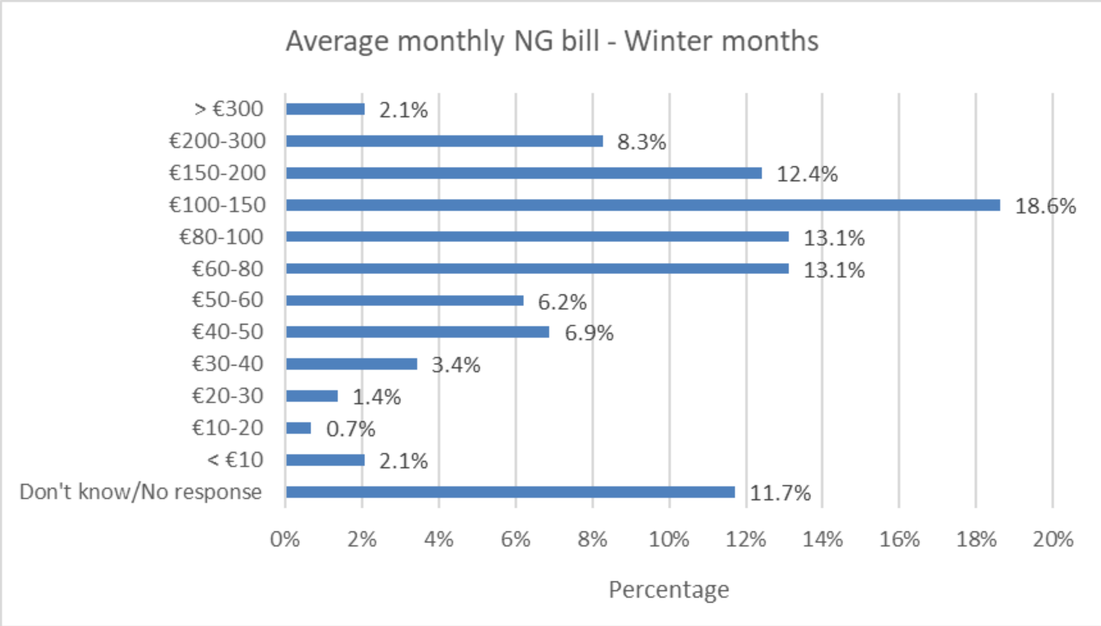


Figure 57. Average monthly NG bill - Winter months

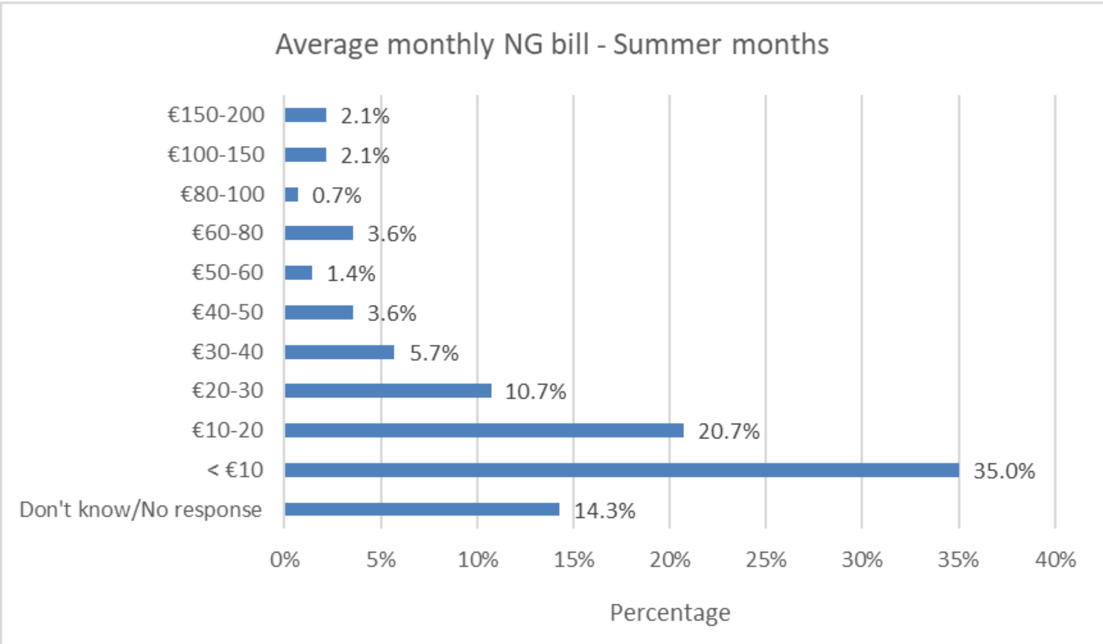


Figure 58. Average monthly NG bill - Summer months

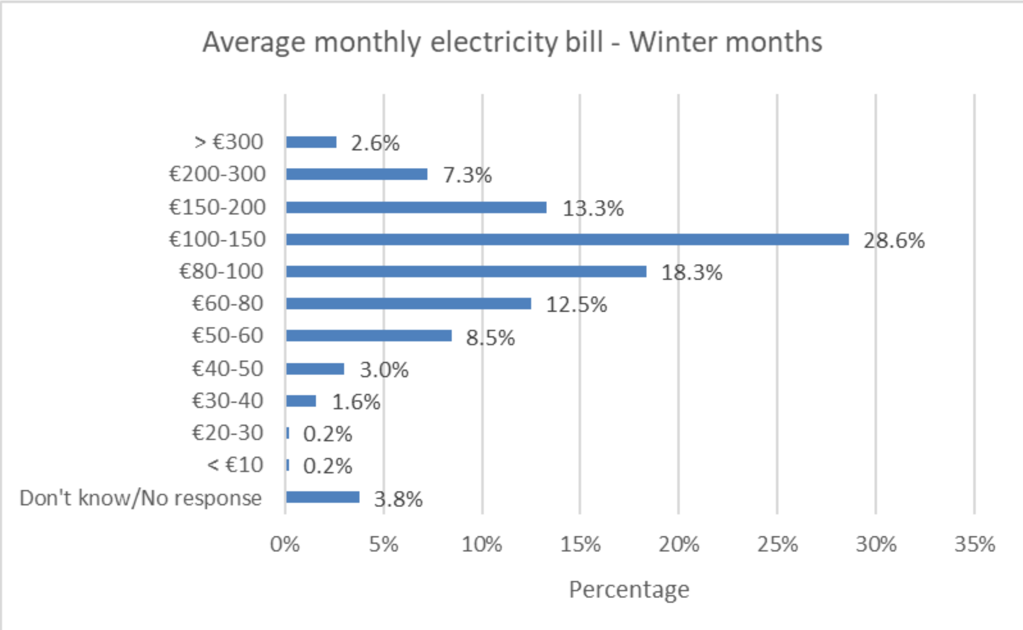


Figure 59. Average monthly electricity bill - Winter months

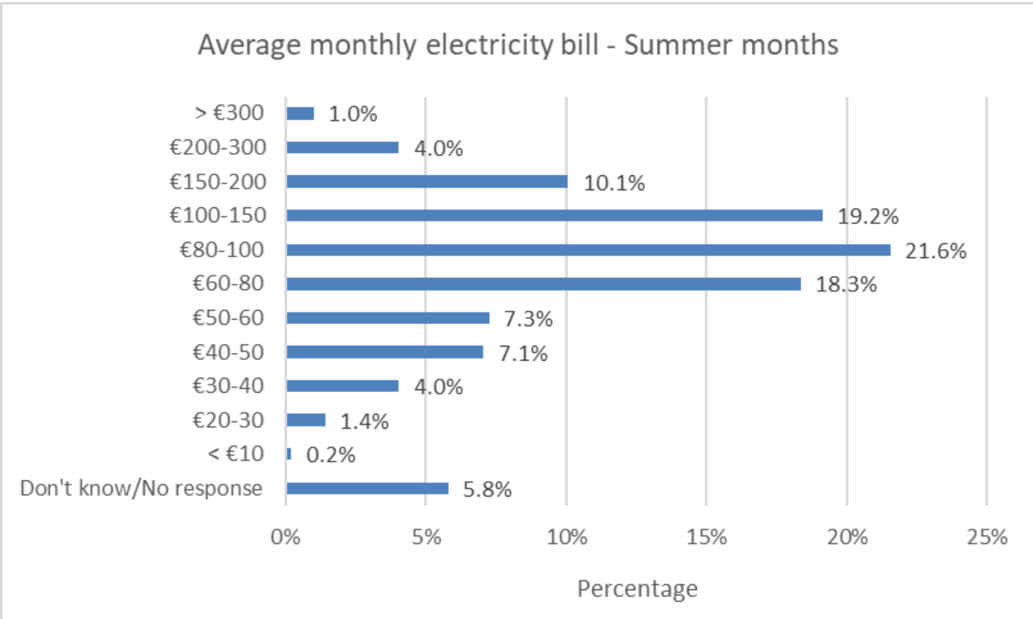


Figure 60. Average monthly electricity bill - Summer months

About 20% of those who use central heating systems fired by oil, firewood/pellet and LPG (it is noted that only two households use central heating systems with LPG) said that they didn't know how much money they spend during the winter period and didn't provide an answer. This percentage is reduced to about half for those households using natural gas and to around 5% or less for the electricity bills.

The average cost of heating for main central heating systems with oil, firewood/pellet and LPG is around €580 (min=€80; max=€2,800; s.d.=€461.9)[2]. Those who use natural gas, the average cost per month is €115 (min=€8; max=€350; s.d.=€73.5) in winter and €24 (min=€8; max=€175; s.d.=€29.7) in summer, respectively[3]. Finally, the average electricity cost per month is €123 (min=€8; max=€350; s.d.=€66) in winter and €102 (min=€8; max=€350; s.d.=€56.8) in summer, respectively[4].

The average total energy cost per year is about €1,880 (min=€150; max=€7,900; s.d.=€1,012). The total annual energy and electricity costs are notably lower for houses constructed after 2012; yet, for older buildings there is no clear trend (Figure 61).

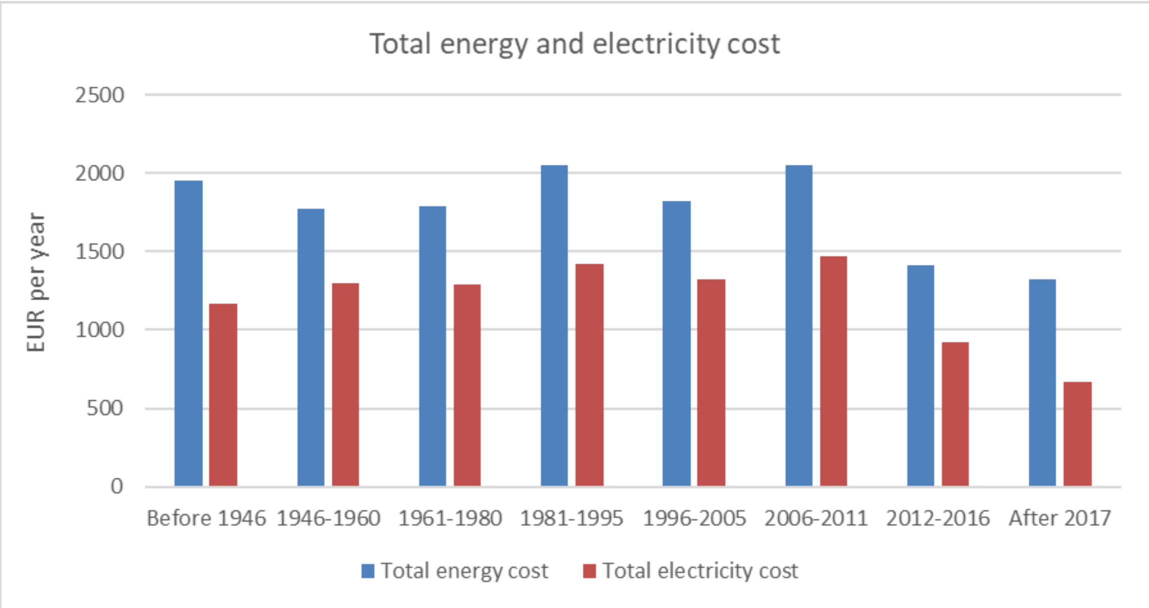


Figure 61. Total annual energy and electricity costs by period of construction year

According to Figure 62, larger homes require higher energy costs. The energy costs of homes with 2 to 4 rooms are about twice as high as those of homes with 1 room. Also, homes with 5 or more rooms have energy costs increased by 20-30% compared to homes with 2 to 4 rooms.

[2] For those households that declared expenditure below €100, an amount of €80 was assumed and for those that declared more than €2,500, an amount of €2,800 was assumed respectively, in order to calculate the basic descriptive statistics.

[3] For those households that declared expenditure below €10 per month, an amount of €8 was assumed and for those that declared more than €300, an amount of €350 was assumed respectively, in order to calculate the basic descriptive statistics.

[4] For those households that declared expenditure below €10 per month, an amount of €8 was assumed and for those that declared more than €300, an amount of €350 was assumed respectively, in order to calculate the basic descriptive statistics.

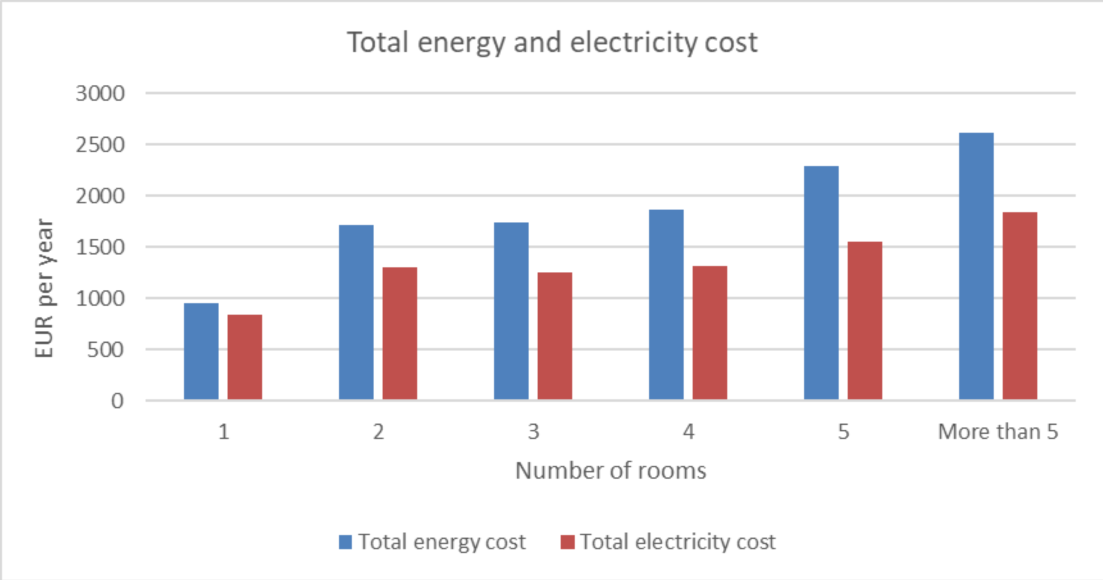


Figure 62. Total annual energy and electricity costs by number of rooms (except for bathrooms and storage rooms)

Differences in energy costs are also observed between the different main heating systems (Figure 63).

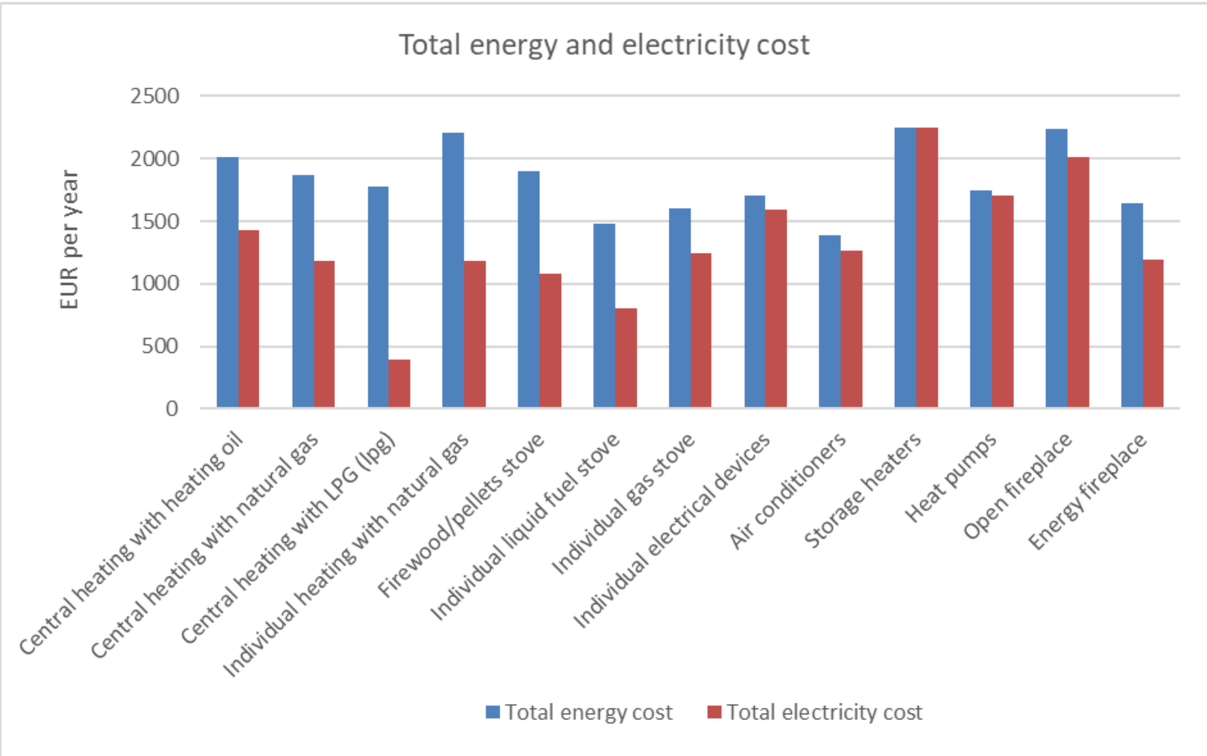


Figure 63. Total annual energy and electricity costs by main heating system

The highest energy costs are observed in houses with individual heating with natural gas, storage heaters and open fireplaces. This is attributed to the high cost of gas, electricity, and firewood, combined with the efficiency of the systems (e.g., in Greece, in winter 2022-2023, the cost of thermal kWh for open fireplaces was about €0.35 compared to €0.18 for energy fireplaces[5]). However, it should be taken into account that more than 80% of households use supplementary heating sources and that for some categories of heating systems there are few observations. Therefore, these findings should be used with caution and further research should be undertaken.

As expected, energy costs are related to the average temperature of the dwelling (Figure 64). On average, there appears to be a difference of 8% in total energy costs between houses with an average indoor temperature below 15°C and those with an average indoor temperature of 15-18°C, respectively. Also, there is a difference of 10% in total energy costs between houses with an average indoor temperature between 15-18°C and those with an average indoor temperature above 18°C. The difference in energy costs is relatively small compared to the difference in indoor temperature. This may be due to the different energy class of the houses. That is, the houses with the lowest temperatures may be, in principle, low energy-efficient houses, which means that higher expenditure is required to achieve even a lower-than-adequate temperature.

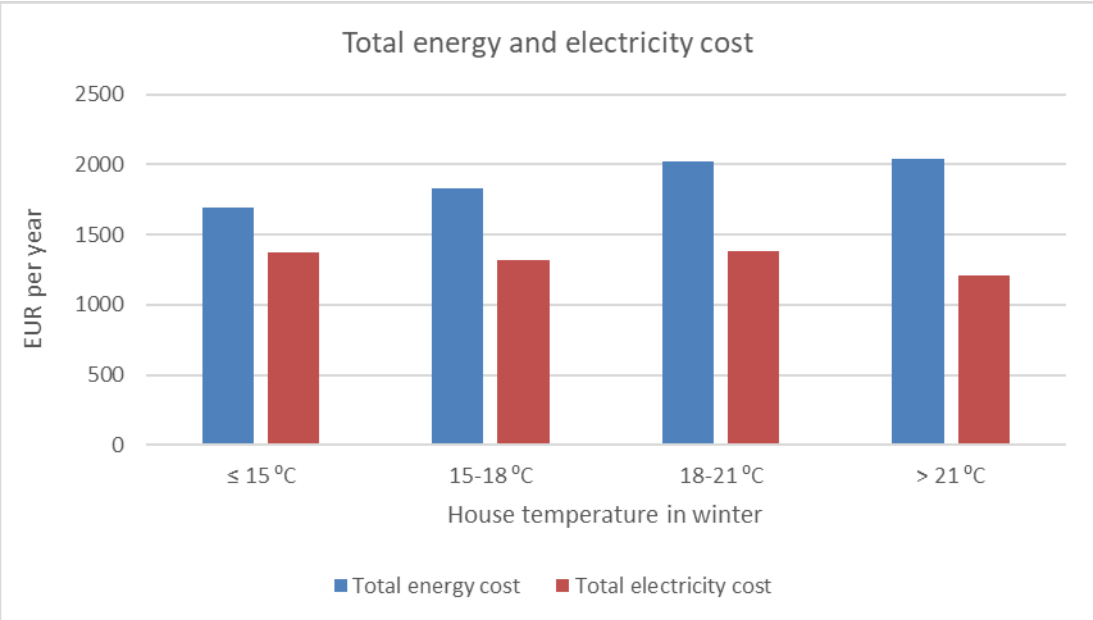


Figure 64. Total annual energy and electricity costs by house temperature in winter

Energy expenses are also affected by households' characteristics. As shown in Figure 65, the higher the number of household members the higher the energy costs. However, this increase is declining. From a one-member to a two-member household the increase is, on average, 28%, from a two-member to a three-member household is 18%, from a three-member to a four-member household is 9.4% and from a four-member household to a household with five or more members

[5] https://t.ly/QwjO0

is 8.6%. Furthermore, households with children less than 5 years old, pensioners and persons with disabilities or long-term illness spend more to meet their energy needs. On the opposite side, households with unemployed persons tend to spend less (Figure 66).

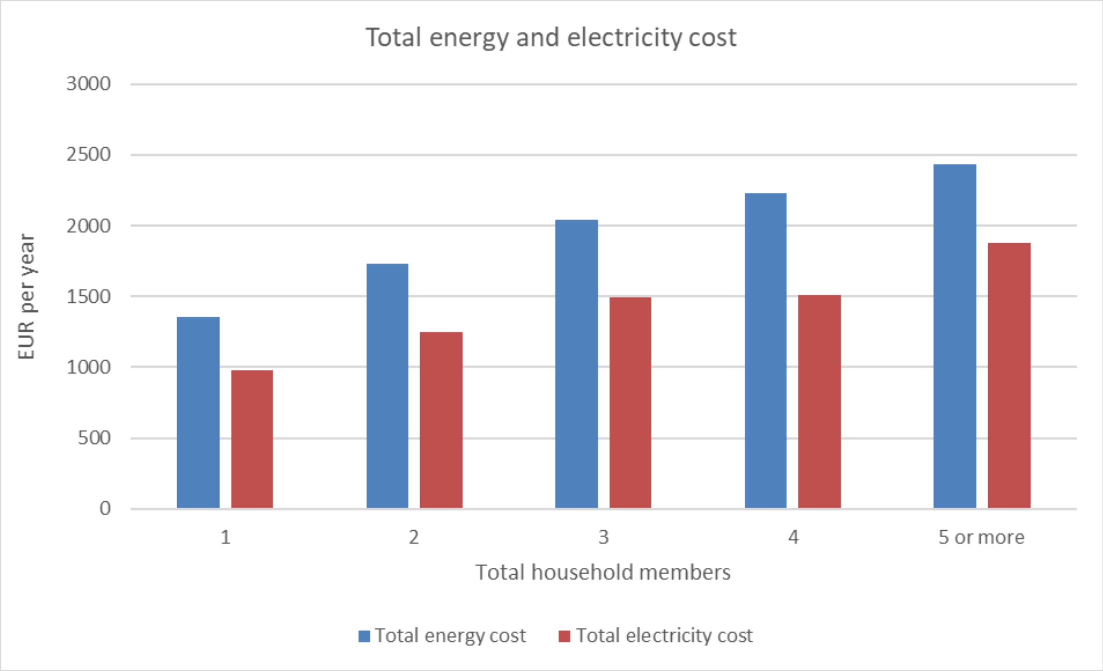


Figure 65. Total annual energy and electricity costs by total household members

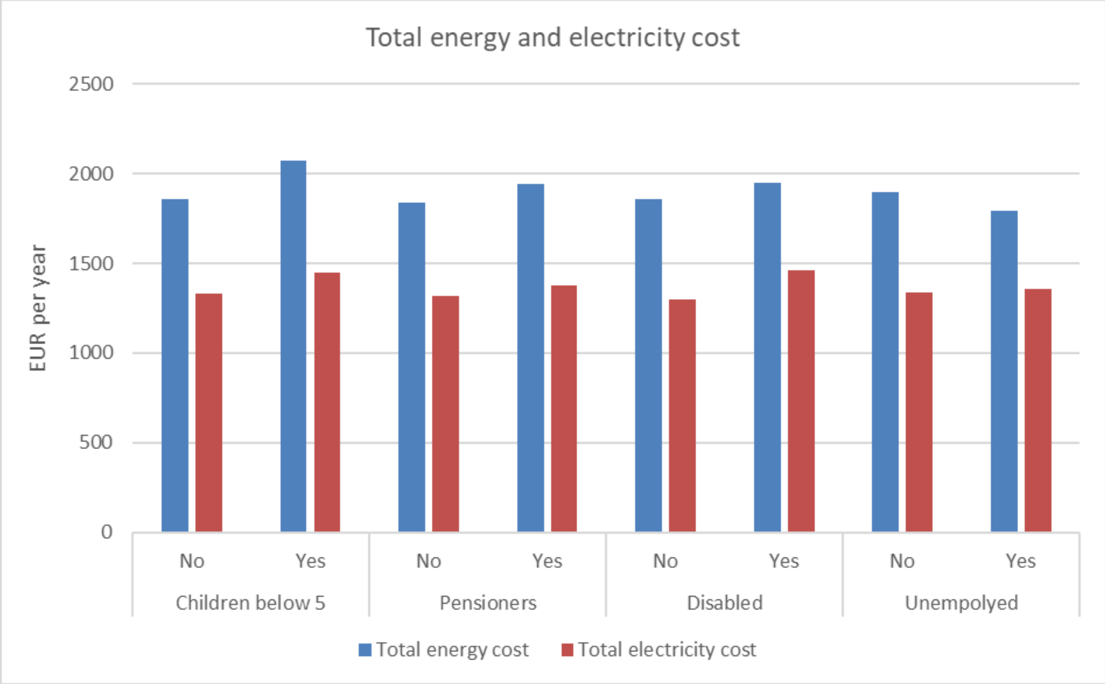


Figure 66. Total annual energy and electricity costs by specific household characteristics

Finally, households that live comfortably on their income spend more money than they claim to simply cover their needs or find it difficult to cover their expenses. However, the difference is relatively small (around 100-150 euros per year), suggesting that energy is an inelastic good.

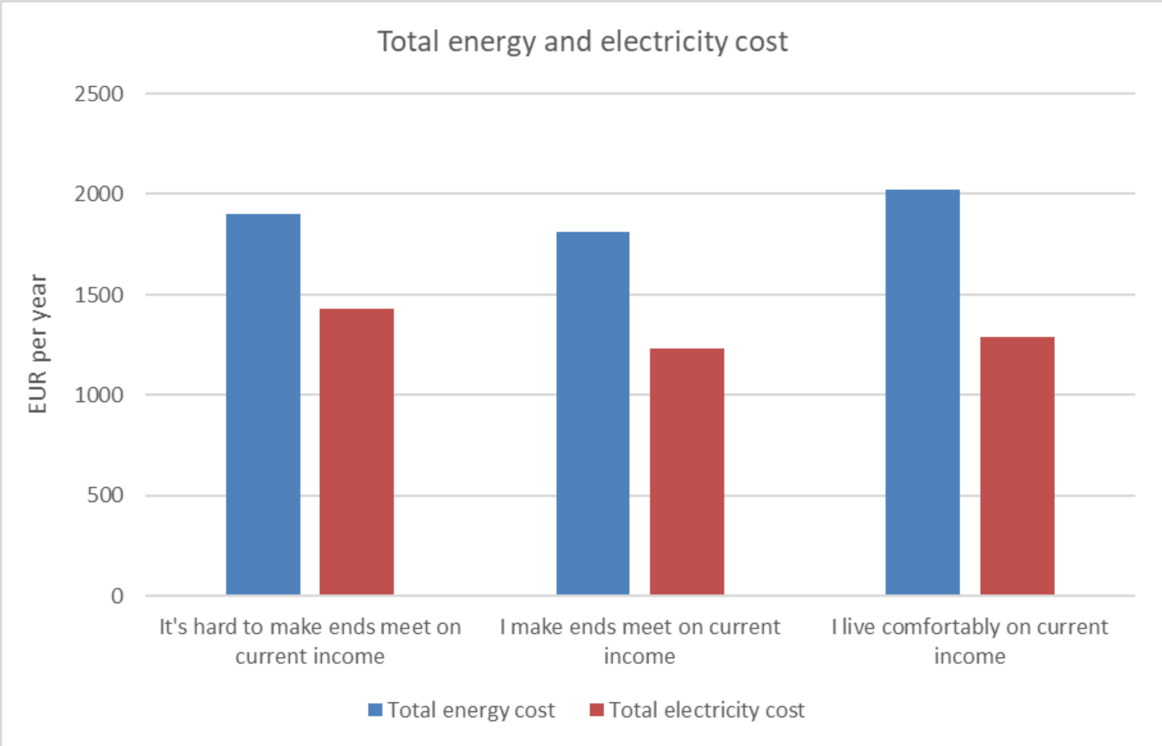


Figure 67. Total annual energy and electricity costs by self-declared income adequacy

2.6 Energy efficiency awareness and behavioural issues

The survey explored issues related to implementation of energy-saving measures, participation in energy saving subsidy programmes, awareness about such programmes, etc.

As presented in Table 7, about one-third of the households have installed energy efficient windows and doors and solar water heater, one-fifth have insulated the walls, floors, and ceiling of their houses and have bought energy efficient appliances, and more than 10% have replaced their heating/cooling systems. Replacement of old lamps with energy-saving ones is, by far, the most popular energy saving measure (implemented by about 62% of the households), most probably because it is a relatively cheap measure with a short payback period. On the other hand, the least popular measure is the installation of photovoltaics on the roof for electricity production (only 2% of the households have installed PV panels and more than 37% claim that they are not thinking about this measure at all).

The attitude of respondents towards roof PV has three main reasons. The first one is practical. Most of the houses in the pilot area are multi-family apartment buildings and the surface area of the roof, combined with the existence of solar water heaters, does not allow the installation of PV for electricity production (at least to an extent that makes sense from an economical point of view). Secondly, subsidy schemes for roof PV have been launched relatively recently and are therefore not very widespread (unlike energy saving schemes for building insulation). Thirdly, there is a negative reputation for residential PV, as some years ago the Greek state introduced a programme to produce electricity from PV on the roof of residential buildings with a guaranteed purchase price. However, after a short time the Greek state unilaterally changed the purchase price of electricity, resulting in many households being significantly damaged.

Table 7. Implementation and willingness to implement energy saving measures

	Energy efficient windows and doors	Wall/ceiling insulation	New heating or cooling system	Installation of solar water heater	New energy efficient appliances	Photovoltaics on the roof	Energy-saving lamps
Yes, in the last decade	33.5%	21.0%	12.7%	30.0%	22.0%	2.0%	61.9%
Yes, in the next five years	2.8%	3.0%	3.0%	5.4%	8.5%	1.8%	9.3%
Yes, in the next five years only if there is a subsidy	23.8%	24.4%	27.4%	19.0%	30.0%	28.2%	9.7%
Not thinking about it/no need	20.2%	27.2%	29.6%	28.4%	21.0%	37.3%	9.9%
I don't know/No answer	19.8%	24.4%	27.2%	17.1%	18.5%	30.6%	9.3%

Another critical finding from Table 7 is that only 5-10% of the households are willing to invest in energy saving measures with high upfront costs in the next 5 years will do so without state support. This percentage is more than 20% for energy-efficient appliances and 50% for energy-saving lamps.

About one-tenth of the households have participated in subsidy programmes (Figure 68).

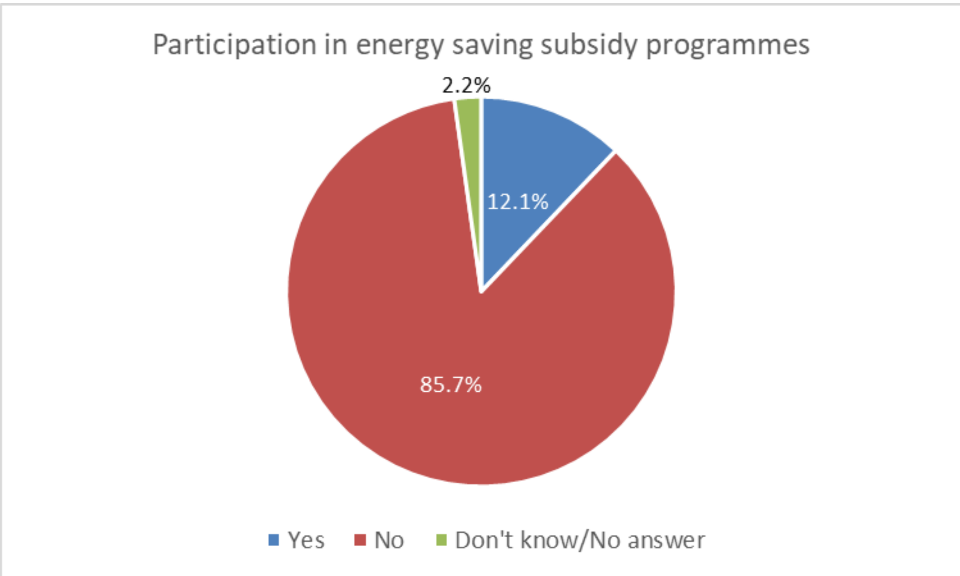


Figure 68. Participation in energy saving subsidy schemes

The three most important reasons (in terms of importance) for not having participated in subsidy programmes are presented in Table 8. Leaving aside those who live in a relatively new and of a good energy class house, the rest of the responses reveal a number of barriers. The most important barrier, which was mentioned by 72.7% of the sample in the three first places, is the inability to invest in high upfront cost measures, which is one of the most acknowledged financial barriers. This is followed by a regulatory barrier, namely the complex administrative process, excessive paperwork, lengthy approval procedures, and bureaucratic hurdles (mentioned by more than 50% of the sample), and another financial barrier, namely the limited access to bank loans (mentioned by around 45% of the sample). Further, a known decision-making barrier, i.e., split incentives between tenants and landlords, and a behavioural barrier, i.e., perceived lack of personal benefit from energy retrofits, were ranked in the three first places by about 26% and 25% of the participants, respectively. Finally, an important knowledge/informative barrier (i.e., lack of awareness about such subsidy programmes) and an organisational barrier related to ownership status (i.e., there are issues with the ownership of the house) were reported by about 20% and 16% of the respondents, accordingly. The latter is a relatively common problem for vulnerable households. They often live in a house that they have inherited from their family but do not have full ownership, as they cannot afford to pay inheritance taxes or other financial obligations that may exist.

Table 8. Reasons for not having participated in subsidy programmes

Reasons for not participating	**First most important reason**	**Second most important reason**	**Third most important reason**
I couldn't afford it, the subsidy was low	36.1%	24.0%	12.6%
I didn't know there were such subsidy programs	4.7%	4.6%	11.0%
I was afraid of bureaucracy	10.9%	20.1%	19.4%
There were issues with the ownership of the house	4.2%	5.7%	5.8%
I couldn't get a loan from a bank	9.7%	20.8%	13.1%
My home is relatively new and of a good energy class	10.2%	8.1%	9.4%
I don't think my energy costs will be significantly reduced	2.0%	7.4%	15.7%
Other	5.5%	3.5%	9.4%
I am a tenant and was not entitled to apply	16.7%	5.7%	3.7%

As far as information about subsidy programmes is concerned, participants seem to adopt a passive attitude, believing that energy providers and municipalities should inform households about existing possibilities to finance energy saving actions (Figure 69). This finding highlights the importance of one-stop shops in encouraging households to engage in such programmes.

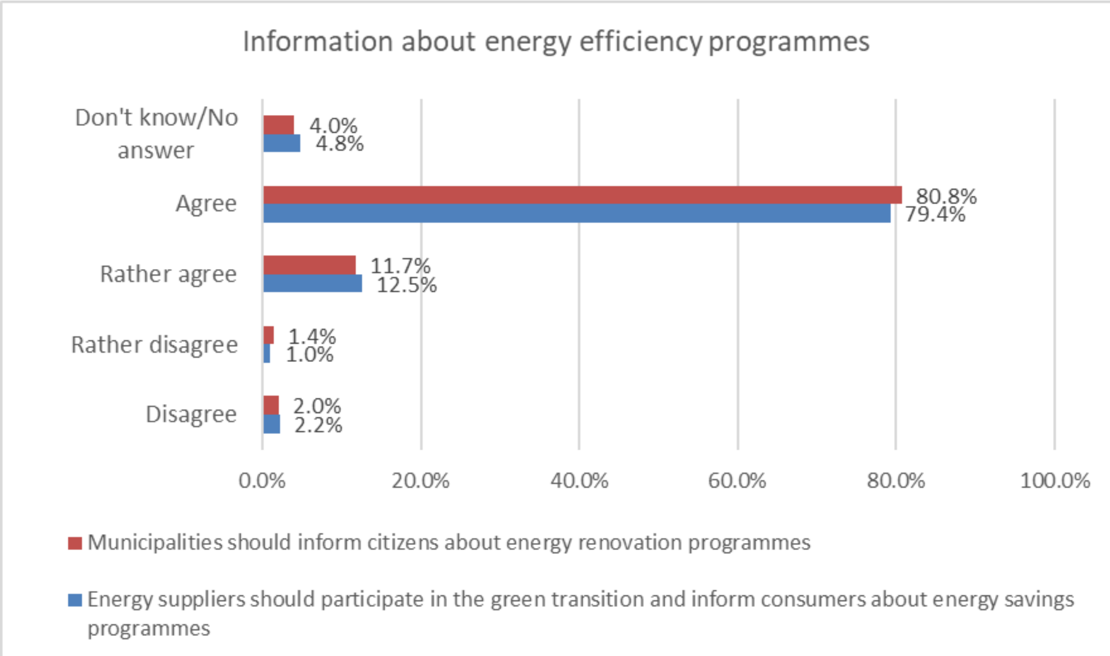


Figure 69. Provision of information about energy efficiency subsidy programmes

Respondents were presented with a hypothetical scenario regarding the energy renovation of their home and were asked to state if they would be willing to pay for renovation and how much money they could give on a monthly basis to repay the project. According to Figure 70, about 80% of the sample would be willing to contribute, 12% said that they couldn't give anything due to financial inability, 1.6% stated that is not interested in investing in energy efficiency and 7.1% concealed their intention and did not answer the question.

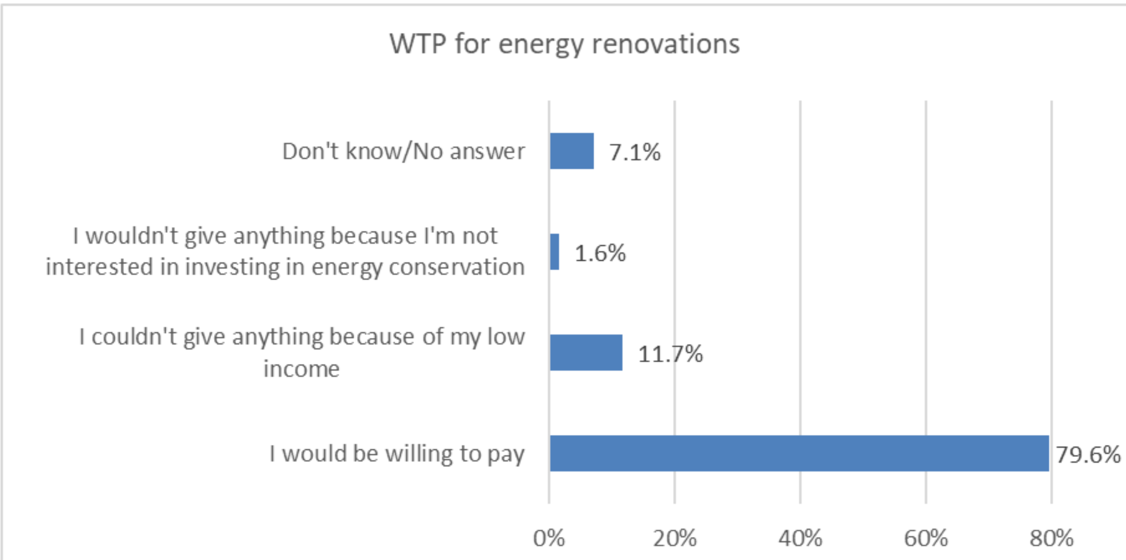


Figure 70. WTP for energy renovation of dwellings

Of those who agreed to pay, about 30% would be willing to give up to €60 per month, 33.5% would pay between €60 and €100 per month, 20% would pay between €100 and €200, and about 10% over €200 (Figure 71).

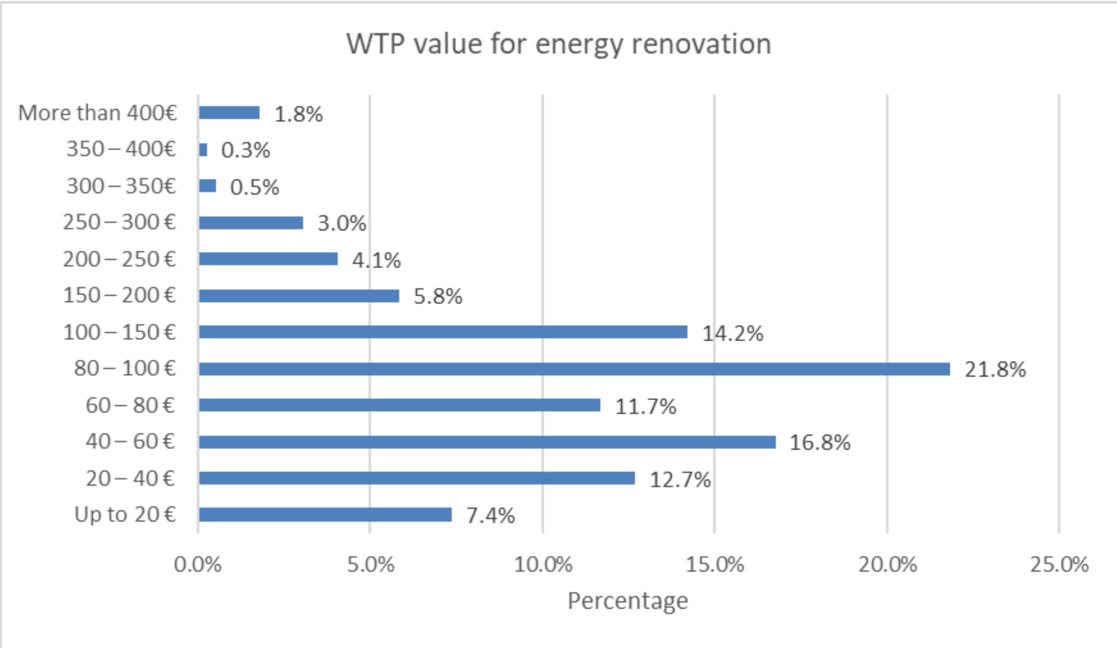


Figure 71. WTP amounts for energy renovation of dwellings

WTP amounts are associated mainly with the income of the household, as presented in Table 9. More specifically:

- Households living in larger houses are willing to pay more for energy renovations, e.g., those who live in two-room houses are willing to pay twice as much as those living in one-room houses and half as much as those living in five-room houses.
- Households owning their house with financial obligations (e.g., mortgage) are willing to pay 60% of the amount that those living in privately owned houses without financial obligations are willing to pay. Similarly, those who rent their houses are willing to pay about 45% of the amount that those living in privately owned houses without financial obligations are willing to pay. The latter, however, may also by a symptom of the landlord-tenants dilemma.
- Households living in houses with temperature over 18°C are willing to pay twice as much as those living in houses with temperature less than 15°C and about 130% of the amount that those living in in houses with temperature between 15-18°C are willing to pay.
- Those who receive social support are willing to pay 35% less than those who are not supported by the State.

- Households that find it hard to make ends meet on current income are willing to pay half as much as those earning enough income to provide for basic needs and about one-third of the amount paid by those living comfortably on their income.
- Households with children less than 5 years old, pensioners, disabled or long-term ill persons, and unemployed persons are paying less than the households.

These results are worrying, as it turns out that those who are most in need of upgrading their homes have less affordability.

Table 9. Factors affecting WTP amounts

Factor	Classes	WTP amount
Number of rooms	1	31.0
	2	59.4
	3	77.1
	4	87.2
	5	103.7
	Over 5	136.1
Your home	It is privately owned without financial obligations (loan, mortgage, etc.)	101.8
	It is privately owned with financial obligations (loan, mortgage, etc.)	80.8
	It is a rental house owned by an individual	62.1
	We have been granted free of charge (family, employer, or other)	44.6
Indoor temperature in winter	≤ 15 °C	47.1
	15-18 °C	77.0
	18-21 °C	101.1
	> 21 °C	110.5
Receive social support	Yes	56.8
	No	87.4
Self-perceived income	It's hard to make ends meet on current income	54.8
	I make ends meet on current income	100.5
	I live comfortably on current income	162.0
Children below 5	No	83.7
	Yes	79.1
Pensioners	No	86.5
	Yes	78.1
Disabled	No	87.3
	Yes	70.6
Unemployed	No	89.4
	Yes	56.3

2.7 Energy poverty, vulnerability and behavioural perspectives

Towards assessing energy vulnerability in Athens Urban Area, several expenditure-based and consensual indicators were calculated from the survey, as follows:

1. Condensation on windows and walls during winter
2. Inability to keep home adequately warm
3. Inability to keep home adequately cool
4. Arrears in energy bills over the last 12 months
5. Electricity/gas supply disconnections in the last 12 months

6. Central heating suspension by decision of a general meeting of the building or due to non-payment of common charges
7. Health problems due to inadequate heating or moisture
8. A composite consensual indicator calculated as follows:

   Composite indicator = Health problems*0.25 + (Inability to keep house cool+ Inability to keep house cool warm)*0.125 + Disconnections*0.25 + Arrears in bills*0.15 + Condensation*0.10

   This indicator receives values from 0 to 1; energy poor households are those having value greater than 0.5.

9. The 'Ten-Percent-Rule'
10. The 2M indicator
11. The M/2 indicator
12. A 'local' 2M indicator (i.e., based on median energy expenditure of the sample)
13. A 'local M/2 (i.e., based on median energy expenditure of the sample)
14. A quantile-based 'Low income/High energy cost' using equivalised income and equivalised energy costs, respectively. To calculate this indicator the quantiles of equivalised income and equivalised energy costs were used.
15. A quantile-based 'Low income/Low energy efficiency' based on five energy efficiency classes (which were based on the existence of energy saving measures), and the four categories of equivalised income.

In addition, cutbacks on essential spending by households (e.g., food, medicines, electricity, heating, how water, kids' education) were investigated to identify those who are energy poor and, at the same time, are forced to cut back on essential goods.

2.7.1 Consensual indicators

As far as the consensual indicators are concerned (Figure 72), the main findings are the following:

- About 45% and 48% of surveyed households claim inability to keep their houses adequately warm in winter and cool in summer, respectively. These percentages exceed 60% in households with a monthly income of less than around €1,000. It should be noted that the inability to keep home adequately warm indicator is significantly higher than the national indicator (i.e., 18.7%) in 2022.
- One-third of the households report condensation on windows and walls during winter. These percentages exceed 50% in households with a monthly income of less than about €700.
- About one-fifth of the households (22.2%) report arrears on their energy bills and about 5% said that their electricity/gas supply was disconnected during the last 12 months. These percentages are relatively low (e.g., the arrears on utility bills national indicator, in 2022, was 34.1%) and are attributed to the emergency energy affordability measures implemented by the Greek government in an effort to shield domestic consumers from the effects of the global energy crisis (i.e., electricity and natural gas subsidies for all

households, extended bill payment date for vulnerable consumers, prohibited disconnections for vulnerable consumers, etc.[6]).

- About one-third of the households (32.7%) report health issues related to inadequate heating and/or the presence of high moisture in the house. Again, low-income households appear more vulnerable to these problems. For example, the percentages are close to or above 60% for households with a monthly income below €850, while they are 20% or lower for households with a monthly income above €1,500.
- Around 18% of the households cannot use the central heating system of the building because its operation has been suspended by decision of the general meeting of the building or due to non-payment of common charges by the occupants of the building.
- As mentioned, a composite EP measure was also developed by the consensual indicators. According to this indicator, the energy poor households (i.e., those having a value above 0.5) is 17.5%. Households with a monthly income below €850 are classified as energy poor at 40% or more according to this indicator, those with an income from €850 to €1,950 euros show an EP rate of about 20%, while in households with an income above €1,950 the indicator is limited to between 3-10%.

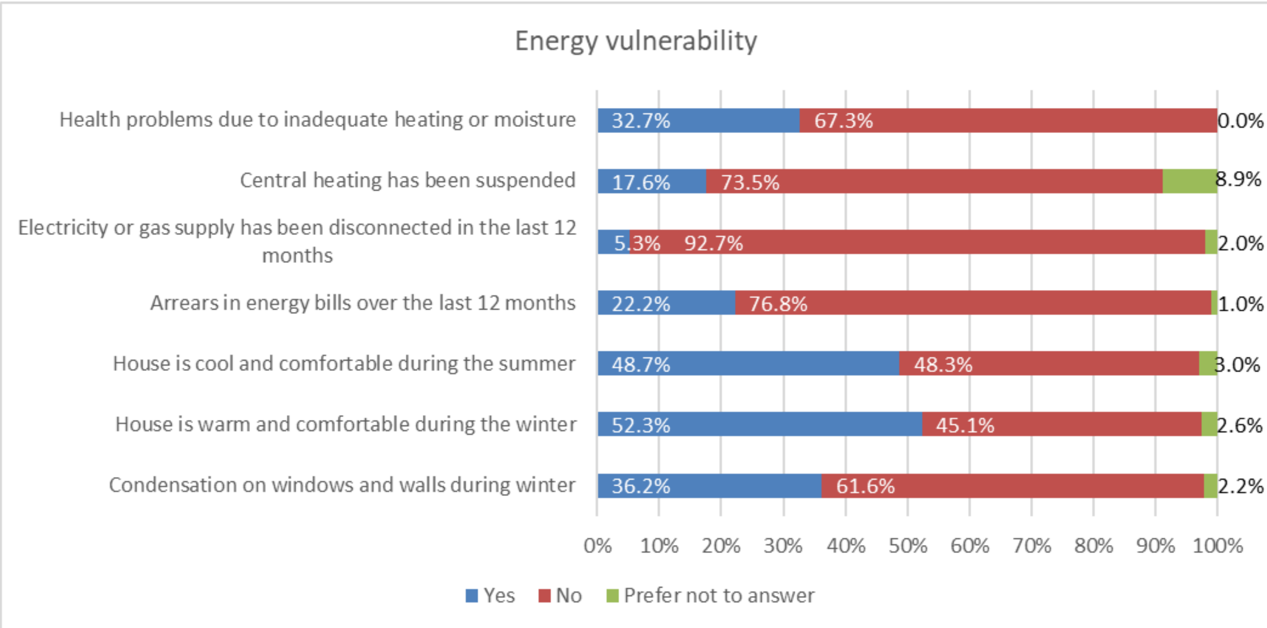


Figure 72. Consensual indicators of energy vulnerability

Moreover, since energy-poor people usually restrict their basic needs (such as food, medicines, etc.) to make ends meet, cutbacks on essential spending by households were investigated. As shown in Figure 73, about 80% of the households have restricted the use of electricity, more than 75% the use of heating, and about 50% the use of DHW in order to be able to pay for energy use during the last 12 months. Moreover, more than half report cutbacks on food purchases, and 65% mention cutbacks on transportation. Not surprisingly, more 'inelastic' goods, such as medicines or

[6] https://www.gov.gr/en/sdg/consumer-rights/connection-to-utilities/electricity/vulnerable-customers

expenses related to kid's education show smaller spending cuts, whereas less necessary goods (e.g., entertainment, shoes, etc.) show significantly higher spending cuts.

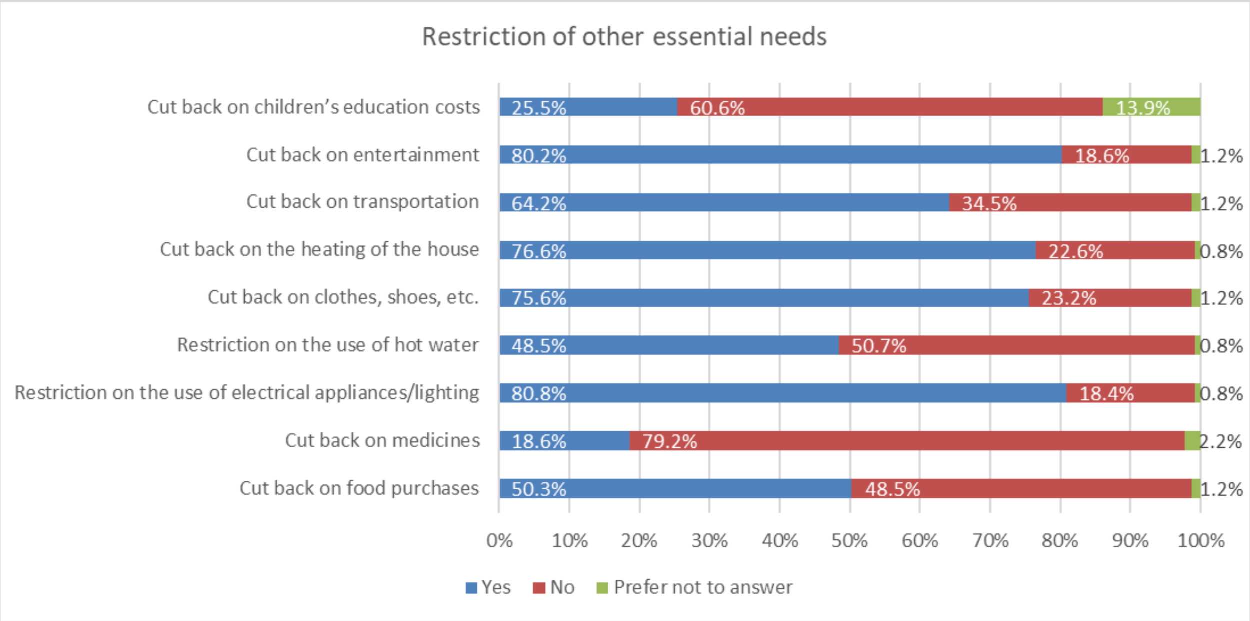


Figure 73. Restrictions of other essential needs in order to pay for energy, over the last 12 months

Table 10 shows the percentage of households that are in the hardest position, i.e., are energy poor and at the same time are forced to cut expenditure on basic goods. About one-third of households have restricted spendings on food but still live in thermally uncomfortable homes, 22% face condensation/mould problems and more than 16% are in arrears on their energy bills. Furthermore, about 10% of those living in energy poverty, according to the consensual EP indicators, are forced to cut medication costs, and 10-15% are forced to cut spending on children's education. Finally, 15-30% limit their transportation costs.

Table 10. Percentage of households that have restricted other essential needs to pay for energy use and are characterised as energy poor (consensual indicators)

	Condensation /Mould	Inadequate warm house	Inadequate cool house	Arrears in bills	Electricity/ gas disconnections	Composite indicator
Cut back on food purchases	22.0%	29.7%	29.1%	16.4%	4.2%	14.1%
Cut back on medicines	9.7%	12.5%	11.3%	7.3%	2.0%	6.5%
Cut back on children's education	12.3%	16.8%	15.4%	9.1%	2.4%	7.5%
Cut back on transportation	26.7%	34.1%	36.4%	18.6%	5.1%	15.4%

2.7.2 Expenditure-based indicators

According to the 'Ten-Percent-Rule' (TPR) (Figure 74), about 35.7% of the surveyed households are characterised as energy poor, i.e., they spend more than ten percent of their net income on energy services.

As an alternative option to capture the burden that energy bills put on households relative to their disposable income, the 2M indicator, which represents the proportion of households whose share of (equivalised) energy expenditure compared to (equivalised) disposable income is more than twice the national median, was used. Moreover, since low-income households that underconsume energy services may not be captured by the 2M measure, the M/2 indicator, which indicates households whose absolute (equivalised) energy expenditure is below half the national median was also calculated. Given that the Household Budget Survey 2022 data was unavailable, the national energy expenditure median had to be estimated using the 2021 national median (i.e., €1,162.92), the harmonised index of consumer prices (HICP) for electricity, gas and other fuels (i.e., 150.56 in 2022, compared to 105.16 in 2021)[7] and the median household income[8] from Eurostat, and an average short-run price elasticity for electricity in Greece (equal to − 0.48) from a recent study (Kostakis & Lolos, 2022). The national energy expenditure median is estimated at €1,440 and the 2M (2M_nat) and M/2 (M2_nat) indicators are found to be 10.2% and 7.1%, respectively.

In addition, these indicators were estimated at a 'local' level, i.e., using energy expenditure and income data from the survey, to allow comparisons with other indicators calculated by the survey. The 'local' 2M (2M_s) and M/2 (M2_s) indicators are equal to 12.9% and 10.6%, respectively.

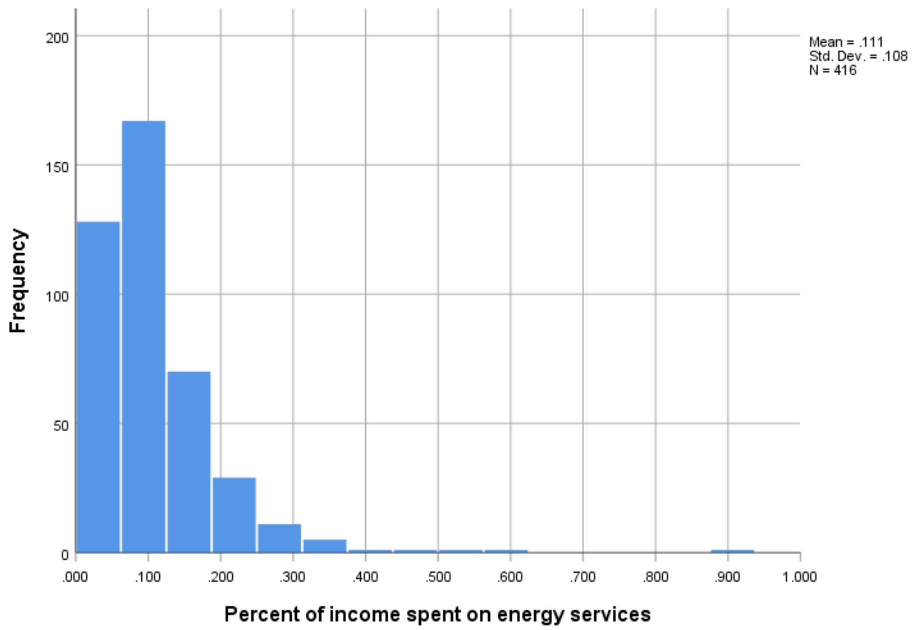


Figure 74. Histogram of ratios between income and energy costs

[7] https://ec.europa.eu/eurostat/databrowser/view/PRC_HICP_AIND__custom_7126988/default/table?lang=en
[8] https://ec.europa.eu/eurostat/databrowser/view/ILC_DI04__custom_7151035/default/table?lang=en

The quantile-based 'Low income/High energy cost' (LIHC) indicator was based on the equivalised income and equivalised energy costs of the household. More specifically, to calculate this indicator the quantiles of equivalised income and equivalised energy costs were used (Table 11).

Table 11. Low Income High Costs (LIHC) quantile-based indicator

		Low-income risk			
		Negligible	Low	Medium	High
High energy cost risk	Negligible	5.8%	5.6%	5.6%	8.6%
	Low	6.3%	5.1%	6.8%	5.8%
	Medium	5.6%	6.8%	5.6%	**7.6%**
	High	7.1%	7.3%	**5.3%**	**5.3%**

The percentage of households with high risk due to low income and high energy costs is 5.3%. Nevertheless, if those households with medium income risk but high energy cost risk (i.e., 5.3%) and high risk due to low income and medium energy cost risk (i.e., 7.6%) are taken also into account, the total percentage of energy vulnerable households based on the LIHC quantile-based indicator is 19.2%.

The quantile-based 'Low income/Low energy efficiency' (LILEE) indicator was based on five energy efficiency classes (depending on the existence of energy saving measures, where 1 corresponds to old houses without energy saving measures and 5 refers to houses with insulated walls, roofs, etc., new windows/doors, and energy efficient heating systems), and the four categories of equivalised income. According to the LILEE quantile-based indicator (Table 12), the percentage of energy vulnerable households (i.e., low-income households living in very low energy efficiency homes) is 19.7%. This percentage increases to 35.9%, if households with medium risk due to low income who live in very low energy efficiency homes (i.e., 15.5%) and households with high risk due to low income who live in low energy efficiency homes are considered (LILEE2 indicator).

Table 12. Low Income Low Energy Efficiency (LILEE) quantile-based indicator

		Low-income risk			
		Negligible	Low	Medium	High
Home energy class	Very low	10.8%	12.3%	**15.5%**	**19.7%**
	Low	1.0%	1.2%	0.2%	**0.7%**
	Moderate	7.4%	5.4%	4.4%	3.4%
	High	2.7%	3.7%	1.0%	2.7%
	Very high	3.0%	2.0%	2.0%	0.7%

In general, as shown in Figure 75, there is a negative trend between income and EP based on the expenditure indicators, as the average percentage of energy poor households decreases with income.

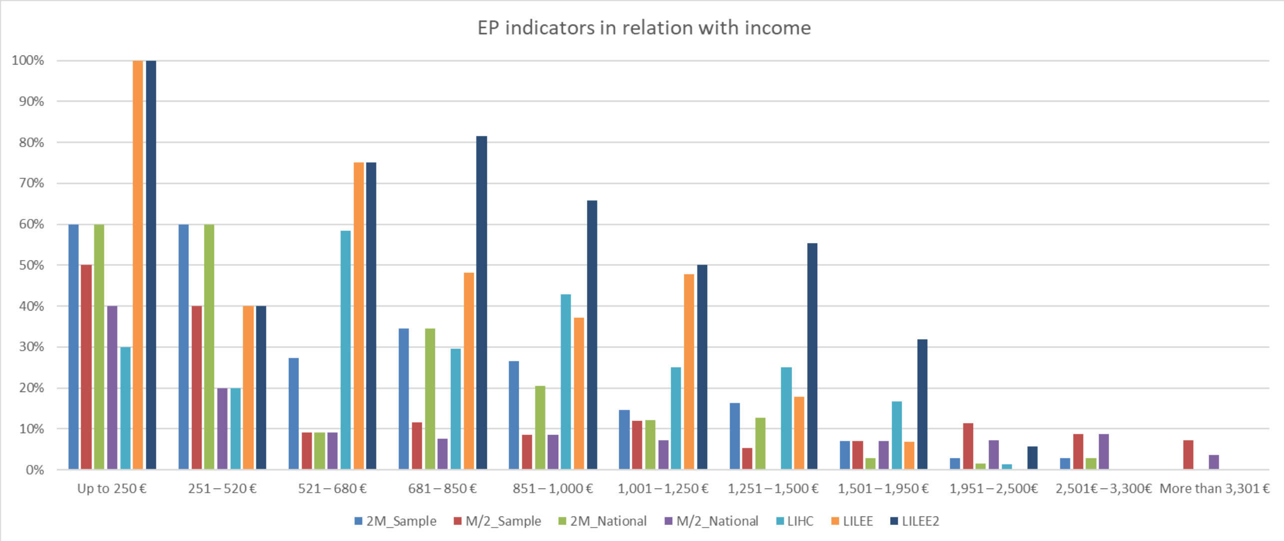


Figure 75. Expenditure-based EP indicators in relation with income

Table 13 presents the percentage of households in the hardest position, i.e., those who are categorised as energy poor based on the expenditure-based indicators and forced to restrict essential needs. According to the LIHC indicator, 5-6% of energy vulnerable households restrict spendings on medicines and children's education, and 10% or more restrict other essential needs. These percentages are comparable to those of indicators LILEE and national 2M. The percentages are about half as high as those for LILEE2 and 'Ten-Percent-Rule' indicators (because there are more households considered energy poor according to these indicators), and almost twice as high for the 'local' 2M and M/2 indicators and the national M/2 indicator.

Table 13. Percentage of households that have restricted other essential needs to pay for energy use and are characterised as energy poor (expenditure-based indicators)

	LIHC	LILEE	LILEE2	10% rule	2M_s	2M_nat	M/2_s	M/2_nat
Cut back on food purchases	10.9%	13.5%	21.6%	23.6%	4.4%	7.5%	5.0%	4.00%
Cut back on medicines	5.1%	6.9%	9.9%	11.1%	1.5%	2.3%	2.1%	2.1%
Cut back on children's education costs	6.3%	8.5%	13.3%	13.7%	2.1%	4.2%	3.1%	2.3%
Cut back on transportation	13.1%	15.4%	25.1%	29.9%	4.8%	9.6%	6.0%	4.8%
Restriction on the use of the heating of the house	12.7%	15.8%	27.3%	30.1%	5.6%	11.6%	7.7%	5.6%
Restriction on the use of electrical appliances/ lighting	13.6%	16.0%	27.5%	31.7%	6.2%	12.9%	7.7%	5.6%
Restriction on the use of hot water	9.3%	12.5%	18.6%	21.8%	4.0%	7.9%	5.8%	4.6%

As mentioned in the literature, each expenditure-based EP indicator measures a different aspect of the problem. For example, as mentioned, the M/2 indicator aims to capture the 'hidden' energy poverty, i.e., households that underconsume energy services, while the 2M indicator aims to capture the excess burden that energy bills put on households relative to their income. This fact is also illustrated in Table 14 that shows the percentage of households appearing simultaneously in two EP indicators (pairwise comparisons). Except in the case of LILEE2 and 'Ten-Percent-Rule' indicators, in all other cases the identification of a household as energy poor by two indicators at the same time is in the range of 10% and much lower, which highlights the need for a multifaceted approach to study the problem.

Table 14. Percentage of households appearing simultaneously in both EP indicators

	LIHC	LILEE	LILEE2	10% rule	Composite	2M_s	2M_nat	M2_s	M2_nat
LIHC	-	7.9%	11.1%	14.5%	4.8%	3.2%	5.6%	0.0%	0.0%
LILEE	-	-	-	12.9%	6.7%	1.2%	2.6%	2.0%	1.6%
LILEE2	-	-	-	20.0%	9.1%	2.4%	4.2%	2.2%	1.6%
10% rule	-	-	-	-	9.5%	5.0%	9.3%	1.0%	1.0%
Composite						2.0%	3.4%	0.6%	0.6%

2.7.3 Social support and perceptions

As mentioned before, electricity and natural gas subsidies were implemented for all households, not only those qualified as vulnerable consumers. In the survey, however, participants were asked whether they had received any social benefits to help them meet their energy needs. In total, 15.4% of the households said that they received some kind of social benefits. Among those who answered in the affirmative, 53.9% said that they were entitled to the social domestic tariff, and 76.3% said that they were beneficiaries of the heating oil allowance. This support, combined with the universal measures that took place, did not have a significant impact on the overall energy costs of the household. In particular, the total annual energy costs for those who received social benefits amounted to about €1,730, compared to €1,910 for those who did not receive the benefits (i.e., there was a reduction of about 9.5% in the total energy cost).

Interestingly and perhaps related to the previous remark, surveyed households believe that the State should support households unable to pay for their energy needs mainly through energy renovation programmes and secondarily through vouchers, fuel rebates, energy price allowances, etc. (Figure 76). This is particularly useful evidence from an energy policymaking perspective, as it highlights the social preference for energy saving measures as opposed to views that argue that households prefer support to cover their energy needs through subsidies.

Finally, as illustrated in Figure 77, respondents believe that energy providers do not support vulnerable households as much as they should. In particular, around two-thirds of them consider that energy providers do not treat low-income consumers fairly. It seems, therefore, that respondents consider that any support measures taken are mainly (if not exclusively) the result of State intervention.

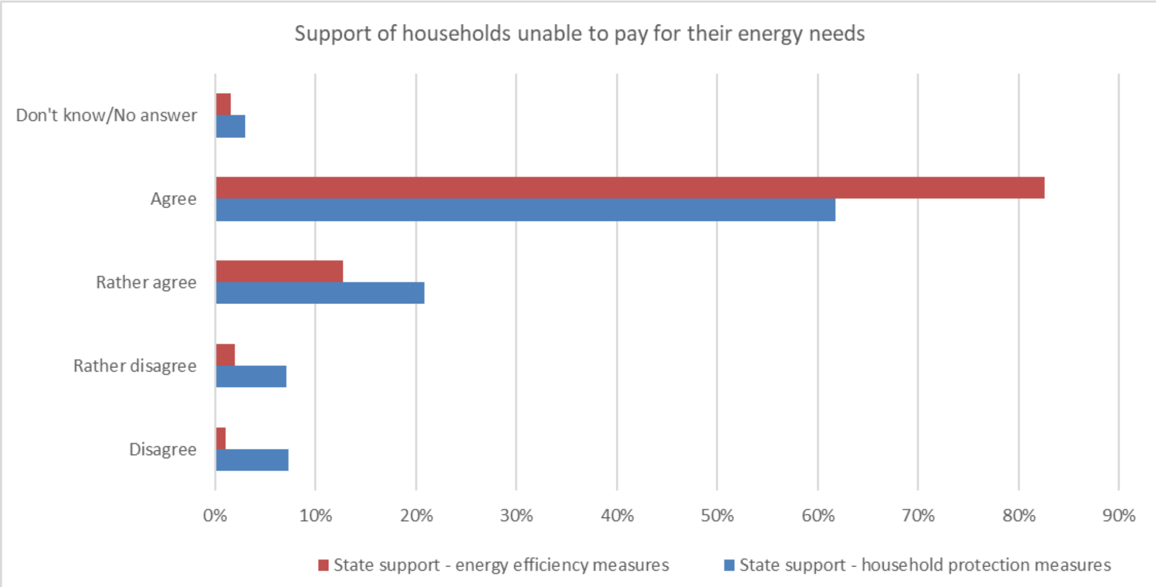


Figure 76. Beliefs about State support measures

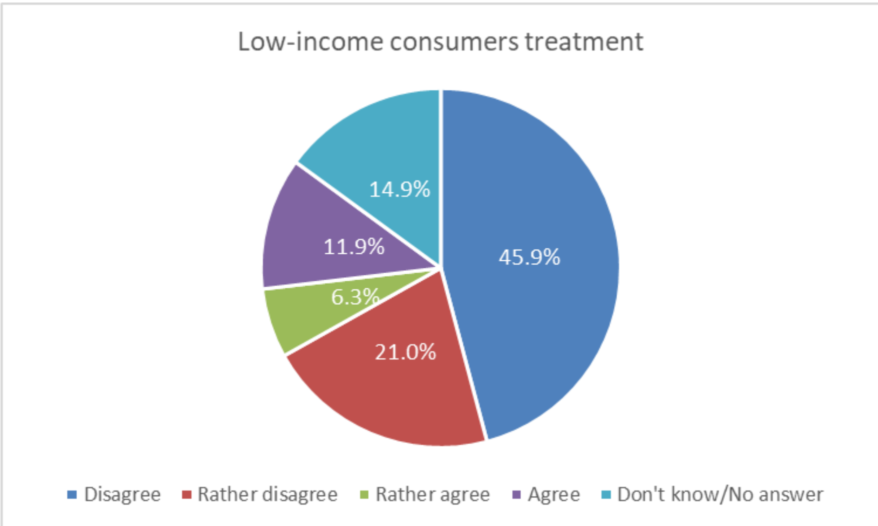


Figure 77. Beliefs about low-income consumers' treatment by energy suppliers

3 Pilot 3 - Riga (Latvia)

3 Pilot 3 - Riga (Latvia)

3.1 Survey administration

Information was collected between June 26th and September 9th, 2023, via an online surveying platform (LimeSurvey). The target group was households living in multifamily buildings residing in Riga, and only individuals 18 years of age or older could participate in the survey.

In total, 935 people followed the survey link they received from either a personal email or were informed via websites and social networks, and 445 people finished the survey. Although the fully filled questionnaires collected exceeded the initial target by 48%, some issues that may have affected the survey should be noted. Initially the responses to the survey were very hard to get. Despite REA best efforts to disseminate the survey among citizens, the majority of the responses were collected during August and September as shown in the graph below.

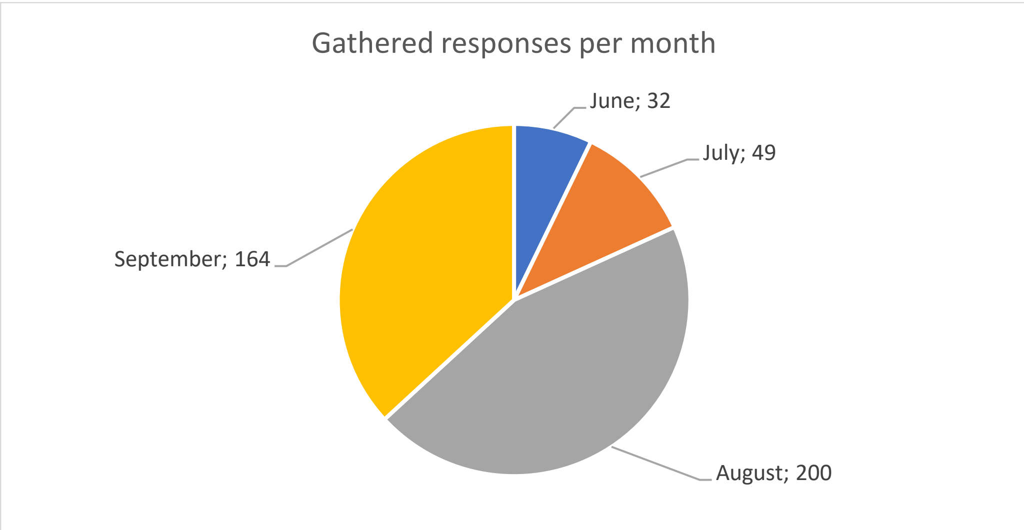


Figure 78. Gathered responses per survey month

The low responsiveness of the inhabitants may be due to lack of interest in summer months to address questions related to energy expenditure and other questions related to energy efficiency. After involving additional dissemination channels, REA managed to reach the target values for the respondents.

3.2 Demographics

As mentioned, a total of 445 households participated in the socioeconomic survey with complete information. The main demographic characteristics are presented in Table 15 and are summarised below.

About 62.7% of the respondents were female and 32.1% were male. The majority of the respondents (24.0%) were between 40 and 49 years old, 21.8% were between 30 and 39 years old, 15.1% were between 60 and 69 years old, and 14.6% were between 50 and 59 years old. Also, 6.5% were more than 70 years old and 4.5% were between 18 and 29 years old, i.e., younger households are underrepresented in the sample.

As far as the educational level is concerned, about three-fourths of the participants (76.9%) had access to higher education.

Most of the households (about 28.5%) include two persons, 24.7% single-person, 18.0% three persons, and 15.7% of four and 7.9 of five or more persons. Furthermore, about 19.1% of the households have children less than 7 years old and 34.4% have students. On the opposite side, about 23.4% of the households have at least one resident who is retired. Finally, about one-fifth of the households who participated in the survey have at least one household member of any age with a disability or long-term illness.

Regarding employment status, more than 79.8% of the households have at least one member who works on a regular, full-time, basis (about 37.8% have two members or more), while 7.2% have at least one member in long-term unemployment.

Table 15. Sample demographics - Riga

Gender	Female	62.7%
	Male	32.1%
	Prefer not to answer	5.2%
Age class	18-29	4.5%
	30-39	21.8%
	40-49	24.0%
	50-59	14.6%
	60-69	15.1%
	>70	6.5%
	Prefer not to answer	13.5%
Household members	1	24.7%
	2	28.5%
	3	18.0%
	4	15.7%
	5	5.8%
	6	0.7%
	More than 6	1.3%
	Prefer not to answer	5.2%
HH with children less than 7 years old	1	13.9%
	2 or more	5.2%
HH with students	1	18.9%
	2	11.7%
	3	3.1%
	More than 3	0.7%
HH with pensioners	1	16.9%
	2	5.8%
	More than 2	0.7%
Full-time employed HH members	1	42.0%
	2	34.6%
	3	1.6%
	More than 3	1.6%
Long-term unemployed HH members	1	6.3%
	2	0.9%
HH members with disabilities/long-term illness	1	15.5%
	2	1.3%
	3	0.2%
Educational level	Primary school	0.7%
	Secondary school	4.3%
	Secondary vocational education	12.4%
	Bachelor degree	33.7%
	Master degree	40.7%
	Doctoral degree	2.5%
	Prefer not to answer	5.8%

Focusing on household economic status-related aspects, the average net monthly income of the households (including allowances, rental income, etc.) is €1,584 (Table 16) and the average total household expenditure for energy during winter per month is €148,65 (Table 17).

Table 16. Net monthly income of all household members

Net monthly income	Percentage
Up to 300 €	1.8%
301 – 600 €	7.0%
601 – 900 €	8.1%
901 – 1200 €	8.1%
1201 – 1,500 €	9.0%
1,501 – 2,000 €	15.7%
2,001 – 2,501 €	11.5%
More than 2,501 €	14.4%
Prefer not to answer	24.5%

Table 17. Total monthly household heating energy expenditure during winter

Total monthly household expenditure	Percentage
Up to 10 €	0.2%
10 –20 €	0.2%
20 – 30 €	0.4%
30 – 40 €	1.6%
40 – 50 €	2.0%
50 – 60 €	3.4%
60 – 80 €	6.7%
80 – 100 €	14.2%
100 – 150 €	22.0%
150 – 200 €	18.4%
200 – 300 €	13.5%
More than 300 €	5.6%
Prefer not to answer	11.7%

On average, the ratio of heating energy expenditure during winter to net income is 9.4%. As shown in Table 18, more than 13.4% of the households claim that they spend more than 20% of their available income to cover their heating energy expenditure needs in winter a 29.4% of the households prefer not to provide feedback.

Table 18. Total heating energy expenditure to net income ratio

Expenditure to net income ratio	Percentage
Less than 5%	7.9%
5%-10%	27.4%
10%-15%	18.4%
15%-20%	7.4%
20%-30%	6.3%
30%-50%	2.0%
Over 50%	1.1%
No response	29.4%

As shown in Figure 79, practically all households with a net income below €900 say they are struggling to make ends meet. households with a net income above €2,500 experience difficulties to a much lesser extent.

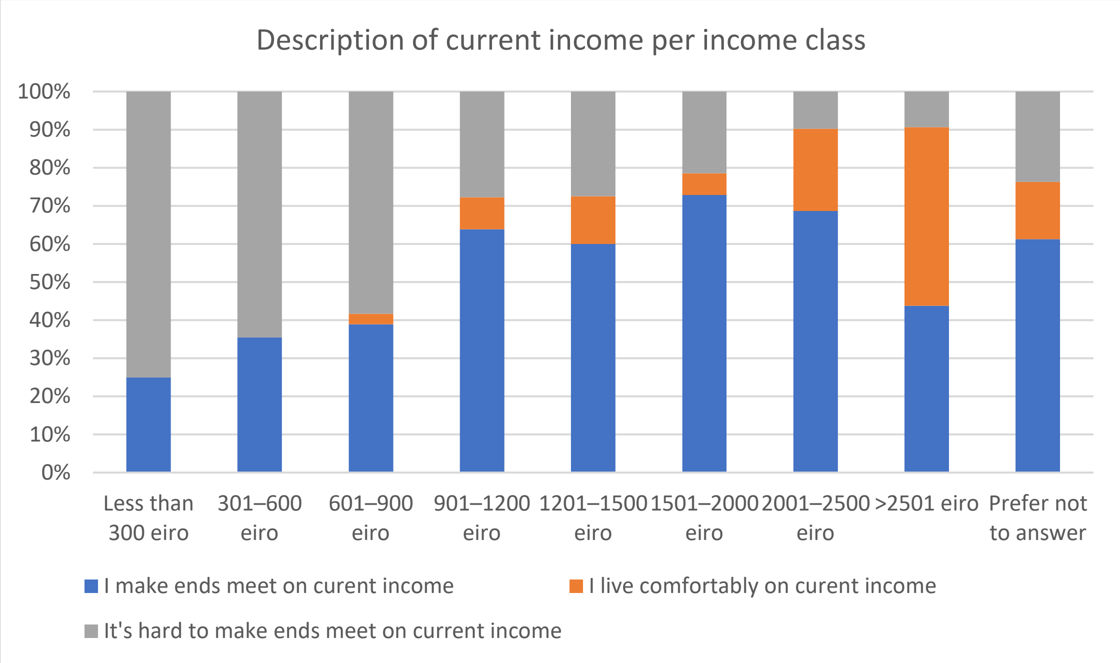


Figure 79. Description of current income per income class

As shown in Figure 80, all studied households indicate, that they can just cover their everyday expenses. However, households with pensioners tend to indicate lower ability to cover the everyday expenses more often than other household groups. Also, households with children (ages less than 7 years old) tend to indicate that it is possible to live comfortably on current income. This may be the specific case of Riga, where parents of young children may have achieved certain professional qualification and tend to earn higher income.

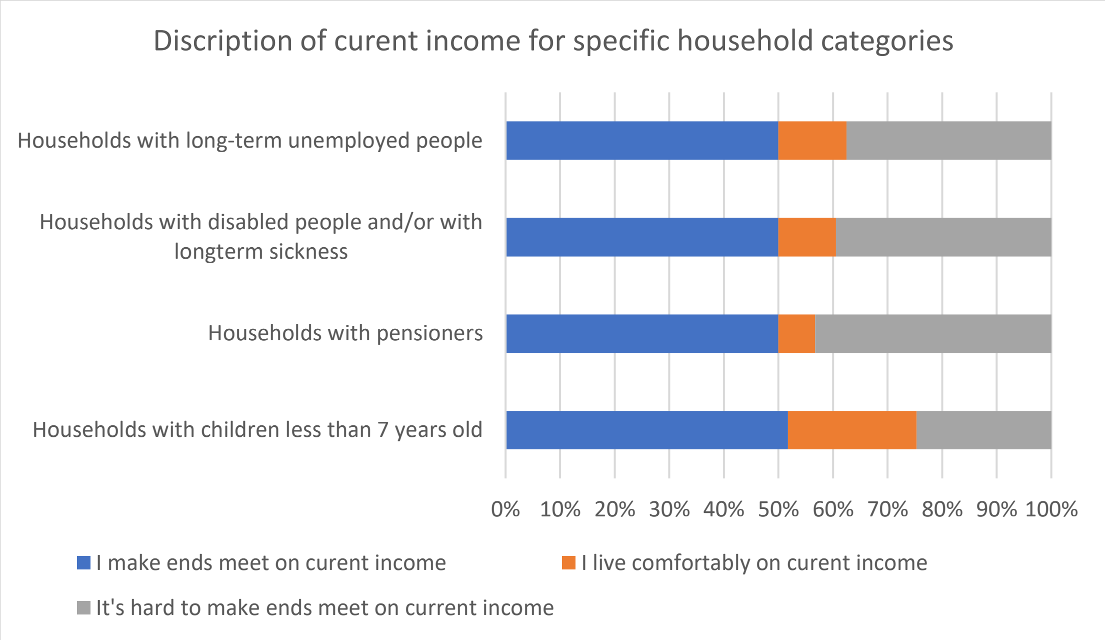


Figure 80. Description of current income for specific household characteristics

3.3 Housing characteristics

As shown in Figure 81, about 60% of the dwellings were constructed during soviet occupation times. These buildings lack basic insulation standards, and their envelope has started to show deterioration signs – in some extreme cases the balcony decay and catastrophic failure (fallen of) have been reported. Further, 25.1% were built between in times before the WW2. Majority of these buildings have some sort of restrictions for envelope upgrades, i.e., parts of the building envelope may have cultural significance which hinders any energy efficiency upgrades, which could harm the overall appearance of the building.

Regarding the total floor area, 1.6% of the residences are less than 25 m^2, 2.2% are between 25-30 m^2, 13.9% are between 30-40 m^2, 20.7% are between 40-50 m^2, 39.7% are between 50-75 m^2 and the rest are over 75 m^2 (Figure 82). Further, nearly 17% have only one room, 37.1% have two rooms, 31.7% have three rooms, and the rest have four or more rooms, except bathrooms and storage rooms (Figure 83).

Finally, as shown in Figure 84, most dwellings (i.e., 59.1%) are privately owned without financial obligations, followed by privately owned with financial obligations (loan, mortgage, etc.) (31.7%) and rental houses owned by an individual (5.2%). Also, a small percentage of dwellings have been provided free of charge by family, friends, employers, municipality or other.

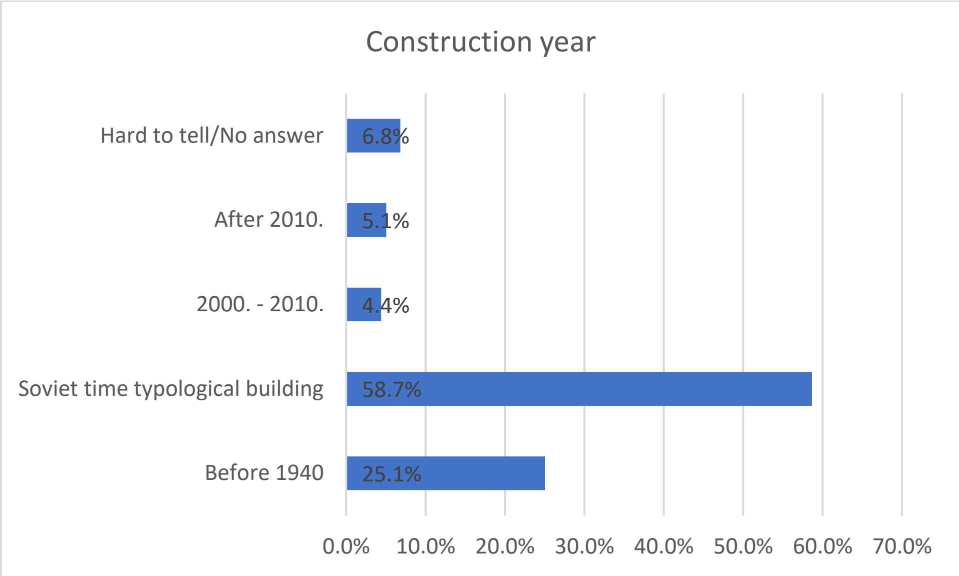


Figure 81. Construction year of dwellings

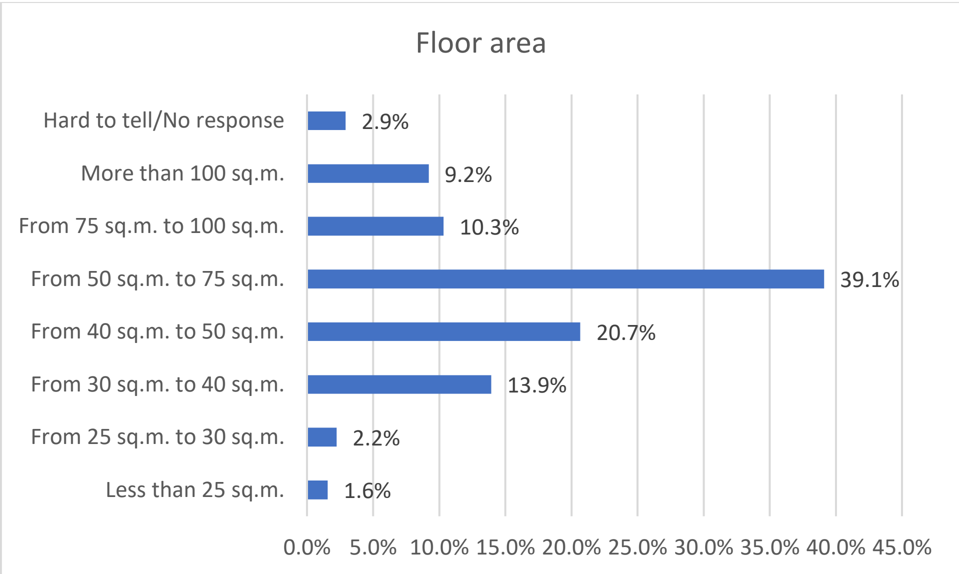


Figure 82. Distribution of dwellings by size

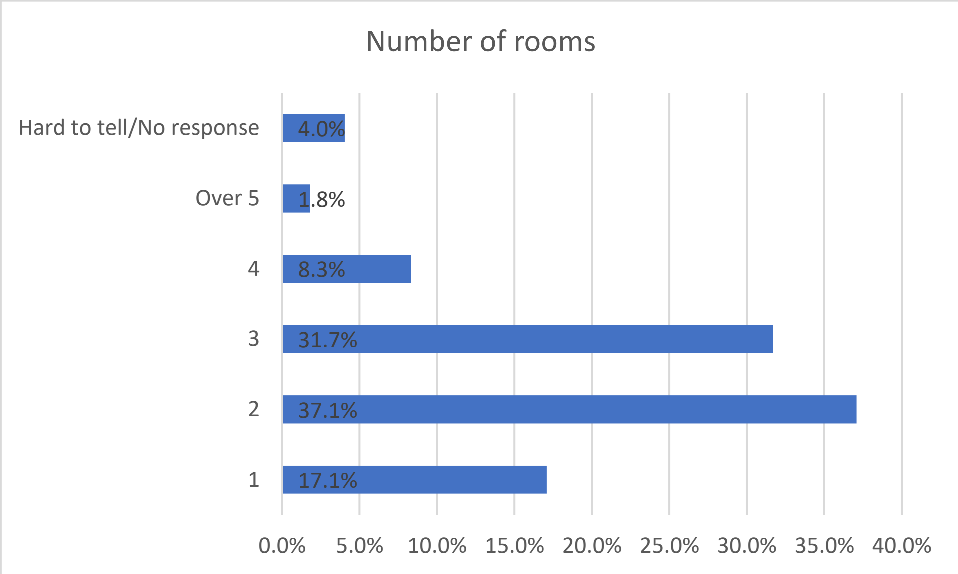


Figure 83. Distribution of dwellings by number of rooms (other than bathrooms and storage areas)

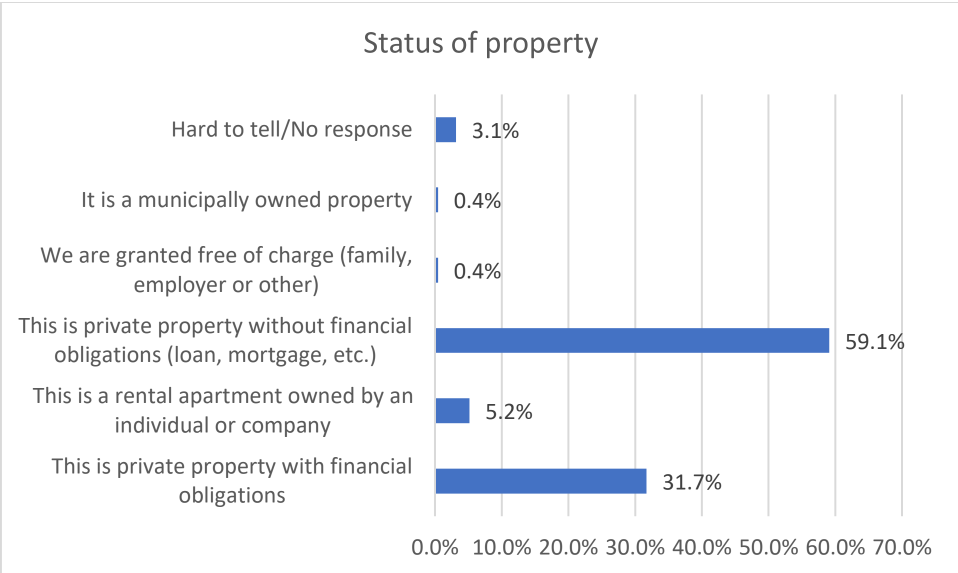


Figure 84. Status of property

3.4 Mechanical systems

As illustrated in Figure 85, 82.7% of the households that took place in the survey heat their homes using district central heating systems, followed by gas heating systems (8.3%). The rest of the households use other systems, mainly wood burning furnaces and electric heaters (both around 2.7%).

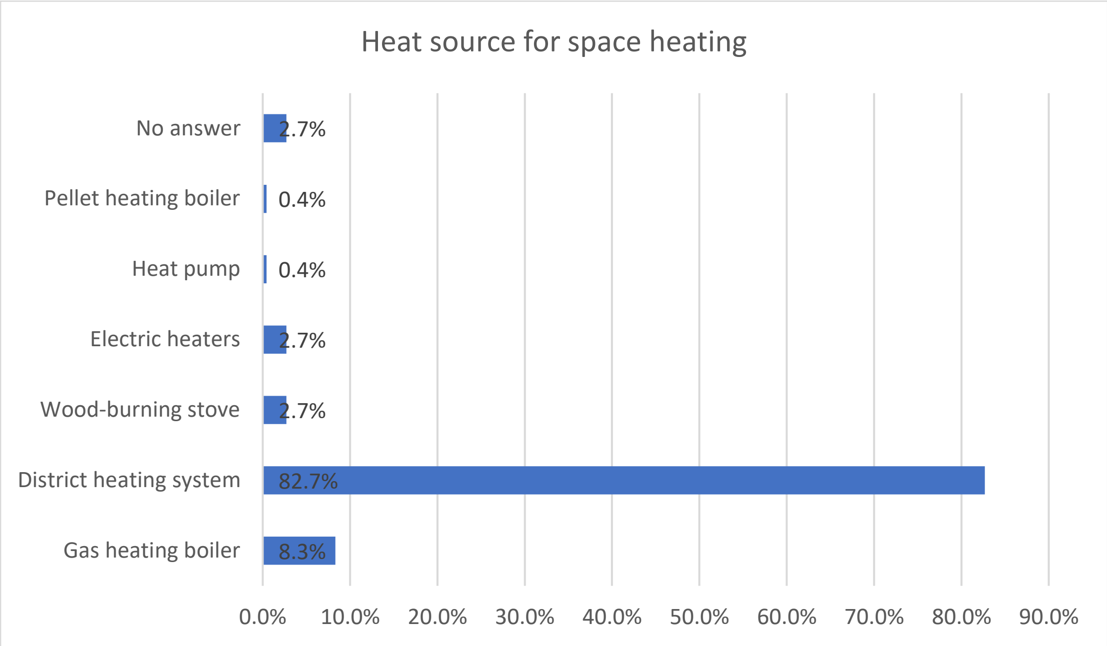


Figure 85. Heating system for space heating

Following Figure 86, it is interesting to note that some of those who have central district heating system use other means of energy to prepare hot water – mainly electric heaters. This mainly is due to the fact, that this way it possible to achieve considerably lower hot water preparation costs during the summer season. Also, in a lot of buildings hot water distribution system is of very poor technical and energy efficiency quality, which raises the cost for each delivered hot water m^3.

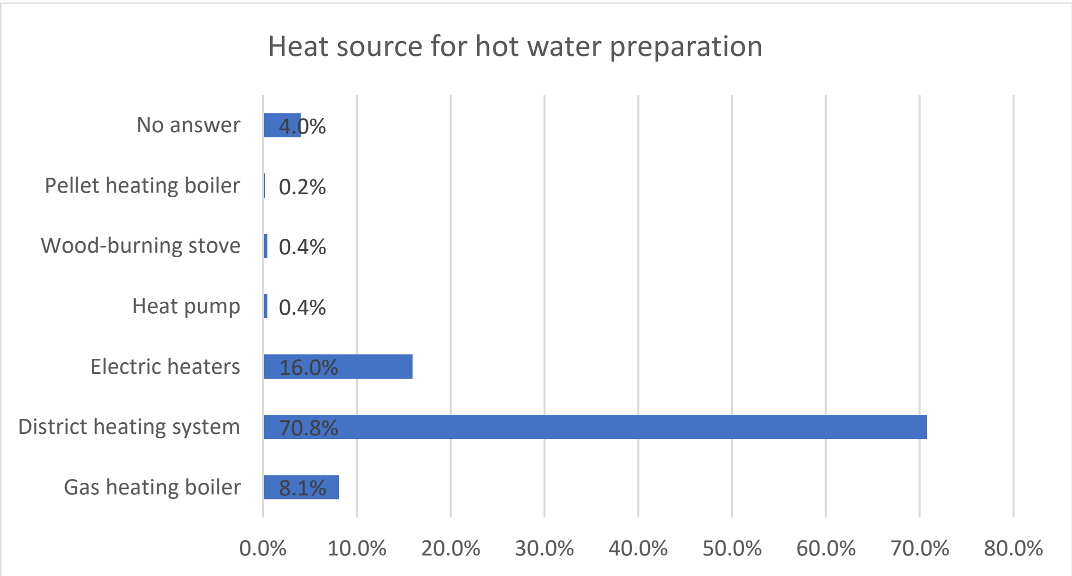


Figure 86. Heat source for hot water production

As majority of the buildings in Riga are connected to the district heating systems there is not expected to be any major variations in heat production sources my declared income level. All multifamily buildings, who are connected to the district heating system, in the vast majority of the cases obtain heat energy for space heating and DHW from the city district heating provider – Rīgas Siltums.

3.5 Energy costs and habits

3.5.1 Heating/cooling awareness and behavioural issues

As shown in Figure 87, in most of the households (about 64.3%) heating system is operated depending on the outside air temperature, which means that during the heating season the heating system is operating all the time, which usually is the case with centralized district heating systems. Another 10.8% don't know how the heating system is operated in their home and 8.3% of the respondents claim, that they do not turn on the heating system. This may be an error or misunderstanding in the questionnaire, as 82.7% of the respondents claimed previously, that their home is connected to the centralized heating system. With centralized heating systems, the inside temperature is controlled mainly by the outside temperature sensor.

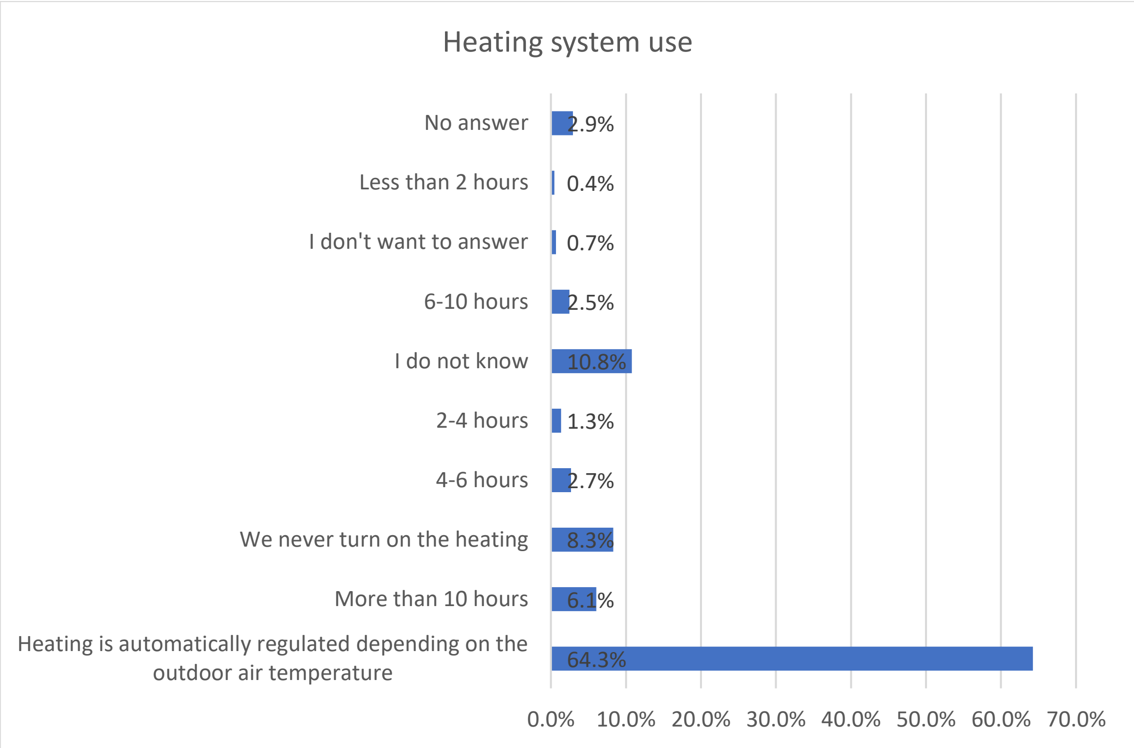


Figure 87. Operating hours of heating system

About 41.6% of the participants said that the ideal indoor temperature is between 18-21ºC (Figure 88) and another 51.5% prefer indoor air temperatures higher than 21ºC. Setting the wrong temperature on the thermostat would overheat the house, leading to wasted energy and excessive energy expenditure.

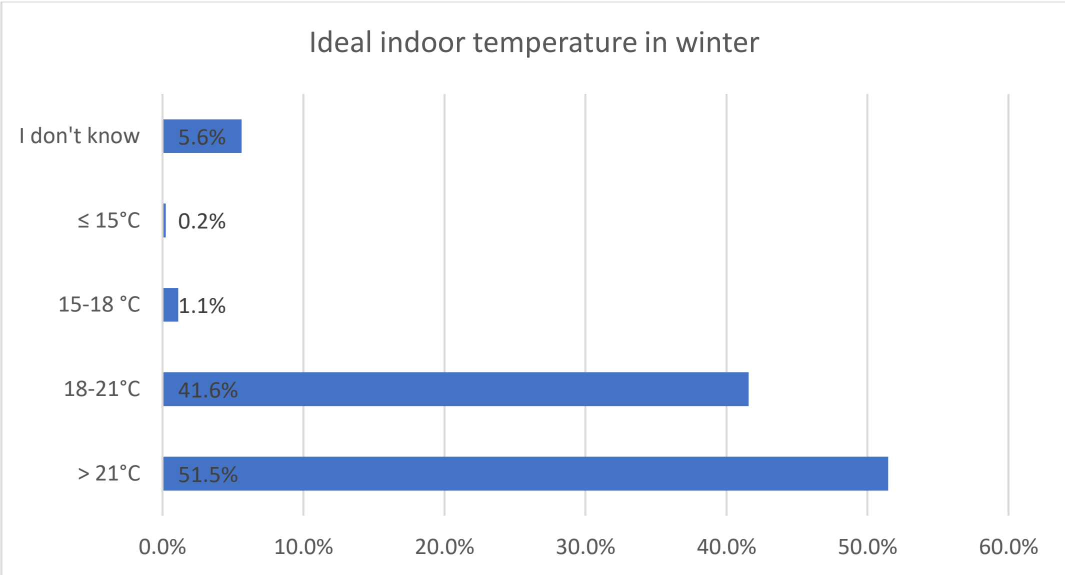


Figure 88. Self-perceived ideal indoor temperature

According to Figure 89, 30.3% of households in the survey can heat their home to a temperature above 21ºC, and 48.1% to the ideal temperature of 18-21ºC. Around 12% of the respondents can't keep their homes adequately warm with indoor temperature of 18ºC or higher. Another 9.7% could not indicate approximate temperature range.

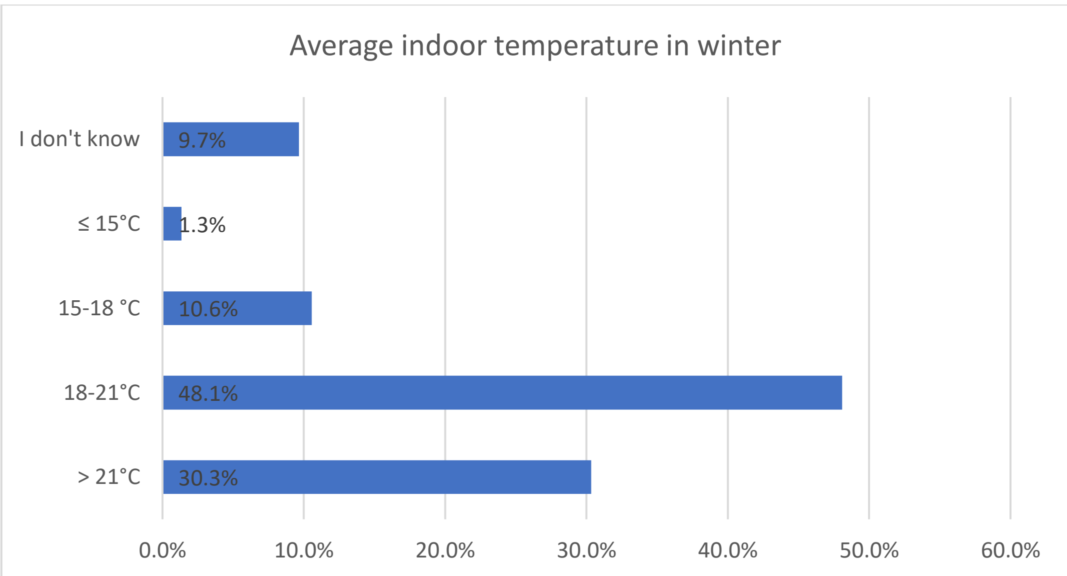


Figure 89. Average indoor temperature

This relation is to be expected since the majority of buildings connected to centralized heating system control the indoor air temperature against the coolest apartment in the MFB. As shown in Figure 90, the percentage of households reporting health problems due to insufficient heating for a house temperature of 15-18ºC is twice as high as the corresponding percentage for a house temperature of 18-21ºC and three times as high as the corresponding percentage for a house temperature above 21ºC.

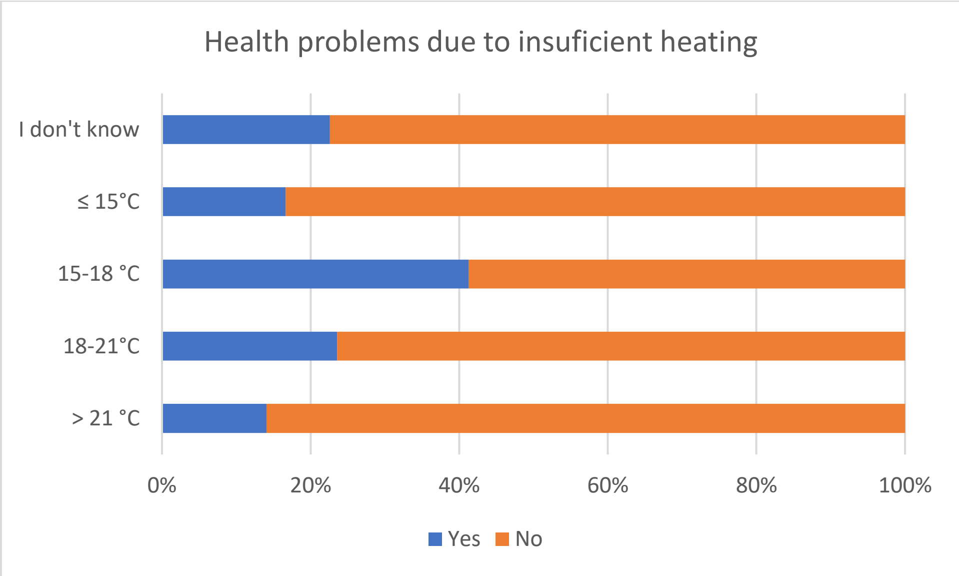


Figure 90. Health problems due to insufficient heating in relation to home temperature

3.5.2 Electricity awareness and behavioural issues

Table 19 summarises the survey responses around electricity-related awareness and behavioural issues.

Table 19. Electricity-related awareness and behavioural issues

I often check the electricity meter reading	Yes	20.2%
	No	78.9%
	Prefer not to answer	0.9%
I compare electricity consumption with previous years	Yes	38.4%
	No	60.7%
	Prefer not to answer	0.9%
I read the consumption (kWh) in the electricity bill	Yes	47.2%
	No	51.9%
	Prefer not to answer	0.9%
I understand the charges on the electricity bill	Yes	25.2%
	No	73.9%
	Prefer not to answer	0.9%
I read the information material that comes with your electricity bill from the electricity supplier	Yes	25.2%
	No	73.9%
	Prefer not to answer	0.9%
I follow the energy-saving instructions given by the electricity supplier	Yes	22.2%
	No	76.9%
	Prefer not to answer	0.9%
I have a digital meter installed and I am regularly informed about my consumption	Yes	43.6%
	No	55.5%
	Prefer not to answer	0.9%

A general conclusion drawn from the answers to the questions posed is that less than half of the respondents take an in-depth interest on the factors related to electricity consumption. Only about 20.2% of respondents pointed out that they regularly check the electricity meter reading and only 38.4% of respondents compare their electricity consumption with previous years. The majority of respondents do not understand the different components of energy price calculation and they do not read the information which comes with their energy bill (around 73.9%). Furthermore almost 76.9% of the respondents do not follow the energy saving advice provided by their electricity provider.

Almost half of the respondents have digital energy meters installed, where they can check their hourly electricity consumption and adjust their behaviour. The responses given suggest that only a fraction of respondents may be adjusting their energy use patterns according to actual hourly electricity prices.

3.5.3 Energy costs

The survey included a number of questions related to households' energy expenditure. The responses are illustrated in the following figures (Figure 91 to Figure 93) and discussed below.

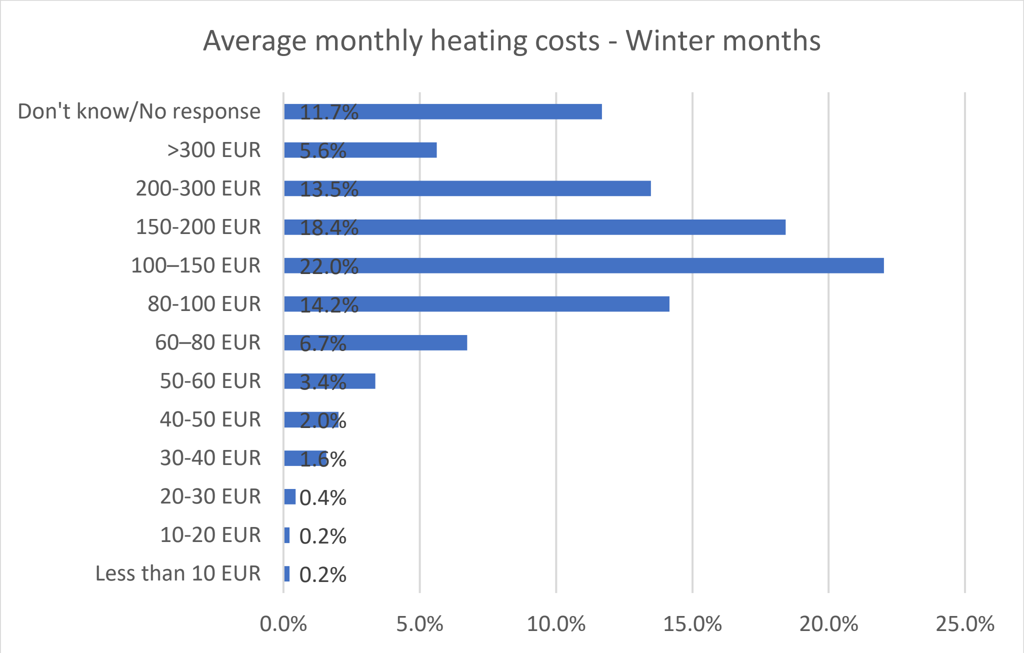


Figure 91. Average monthly heating costs - Winter months

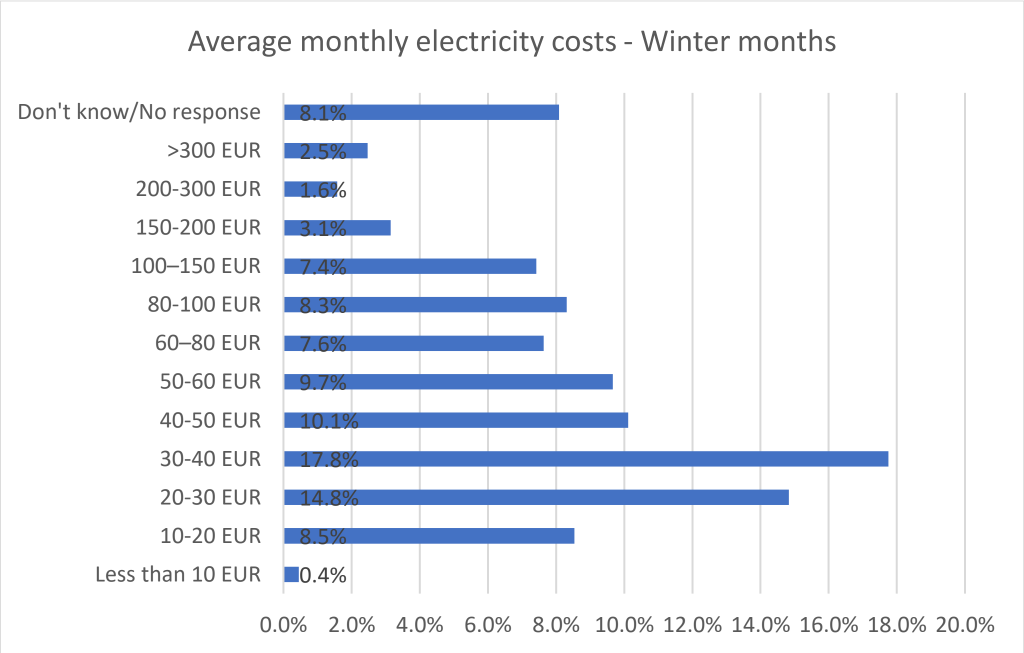


Figure 92. Average monthly electricity bill - Winter months

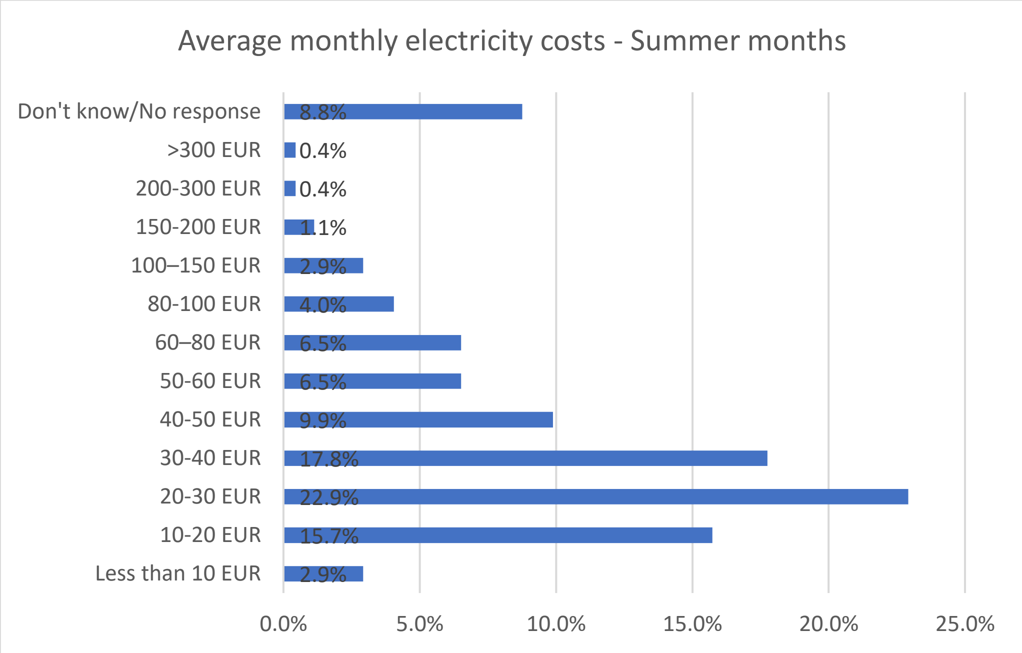


Figure 93. Average monthly electricity bill - Summer months

The average cost of heating during winter period is around €149 per month (min=€8; max=€330)[9], and the average electricity cost per month is €61 (min=€8; max=€330) in winter and €39 (min=€8; max=€330) in summer, respectively[10].

The average total energy cost per year is about €1570,67[11] (min=€109; max=€6105). The total annual heat energy costs are notably lower for houses constructed after 2010; there is a clear trend that the older the building, the higher the reported energy costs. Except for electricity costs, where the highest electricity costs have been reported in buildings constructed after 2010. This may be due to the fact that newer buildings tend to be occupied by wealthiest citizen groups, who may have higher energy expenditure due to higher comfort levels (additional household appliances, additional cooling in summer) (Figure 94).

[9] For those households that declared expenditure below €10, an amount of €8 was assumed and for those that declared more than €300, an amount of €330 was assumed respectively, in order to calculate the basic descriptive statistics.

[10] For those households that declared expenditure below €10 per month, an amount of €8 was assumed and for those that declared more than €300, an amount of €330 was assumed respectively, in order to calculate the basic descriptive statistics.

[11] Yearly heating energy costs are calculated by multiplying average monthly heating costs by 6.5 months, which would equate to 195 heating days, which is about the same as stated in National Building Code in Riga.

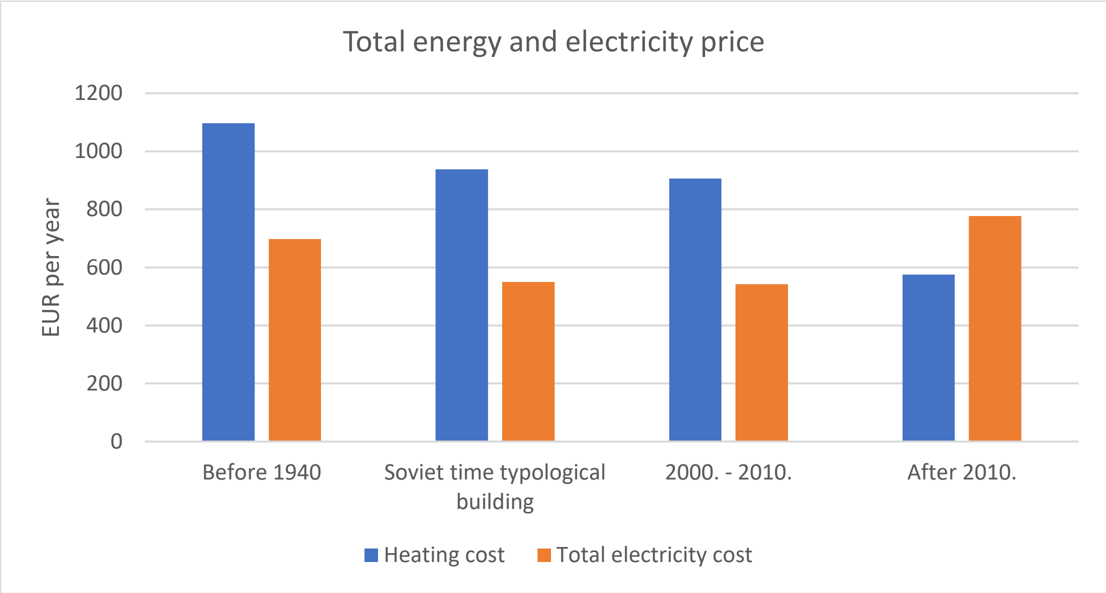


Figure 94. Total annual energy and electricity costs by period of construction year

According to Figure 95, larger homes require higher energy costs. For homes with 1 to 3 rooms the energy cost increase both in heating costs and electricity costs, increases gradually, however for homes with 4 rooms, the reported heating energy costs still rise gradually compared to homes with 3 room, bur the reported electricity costs stay at roughly the same level. For homes with more than 5 rooms, there is a slight decrease in reported heat energy costs, however there is a sharp reported electricity cost increase, which may be due to fact, that partially heat energy may be provided via electric heaters or there may be some errors in respondents perceived energy costs.

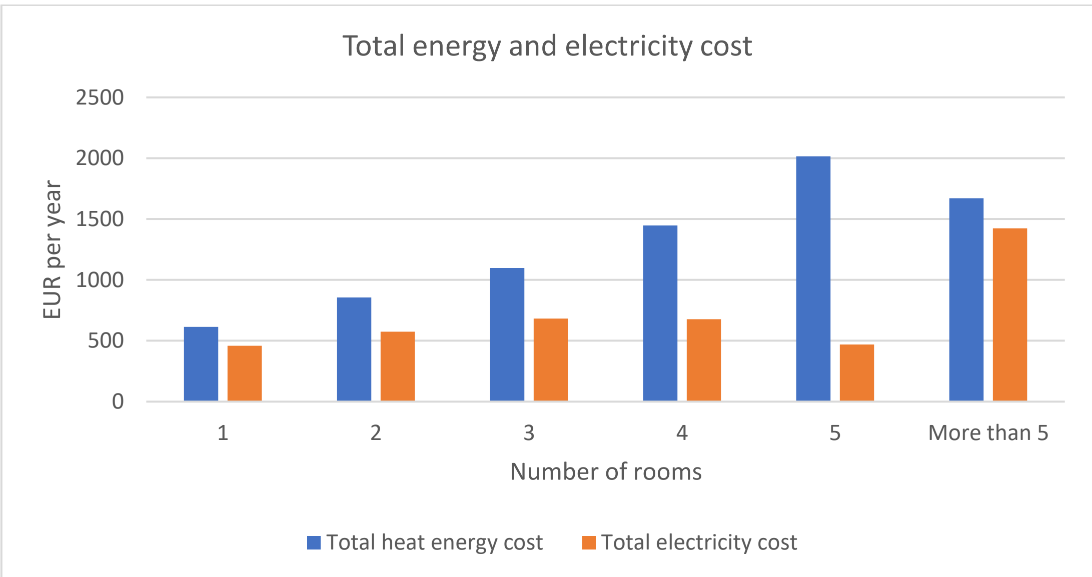


Figure 95. Total annual energy and electricity costs by number of rooms (except for bathrooms and storage rooms)

Differences in energy costs are also observed between the different main heating systems (Figure 96).

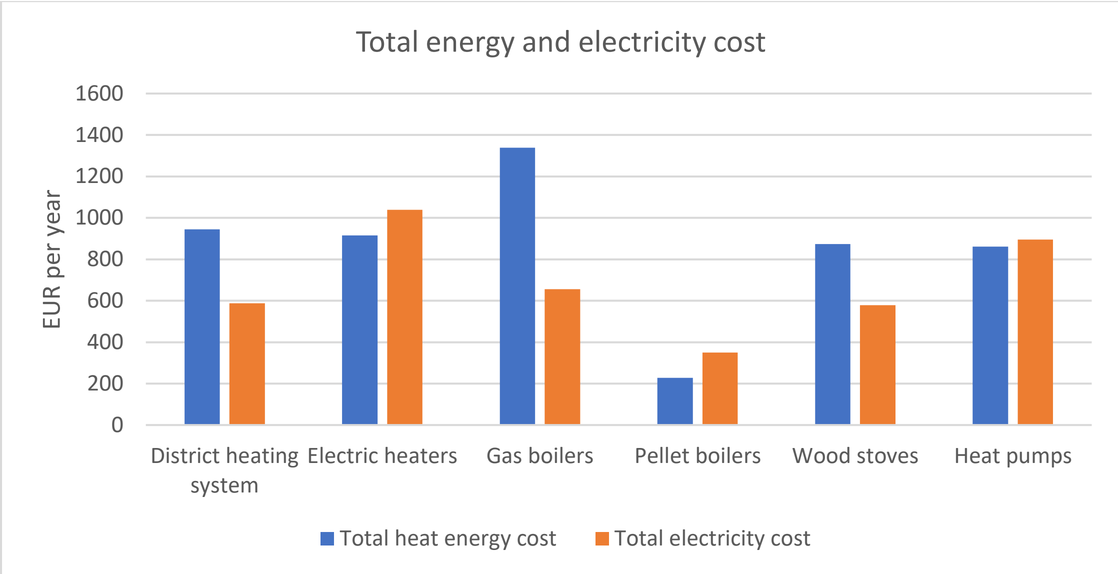


Figure 96. Total annual energy and electricity costs by main heating system

The highest energy costs are observed in houses with gas boilers. This may be due to the fact that respondents gave approximate costs for heating as well as for hot water preparation, as usually this can't be differentiated in the overall gas delivery bill. This is also the case for systems other than district heating systems. Therefore, these findings should be used with caution and further research should be undertaken.

Surprisingly there was no clear trend relating energy costs to the indoor air temperature (Figure 97). The highest reported energy costs are reported in homes, who's inhabitants reported indoor temperatures in the range from 15ºC to 18ºC. This may be due to the fact that in the majority of multifamily buildings there is no possibility to individually regulate indoor air temperature. It is necessary to consider that survey was conducted in the end of summer, therefore it can't be clearly established if the reported temperature values are from those measured in the paste heating season or subjectively defined based on memories and feelings from past heating season.

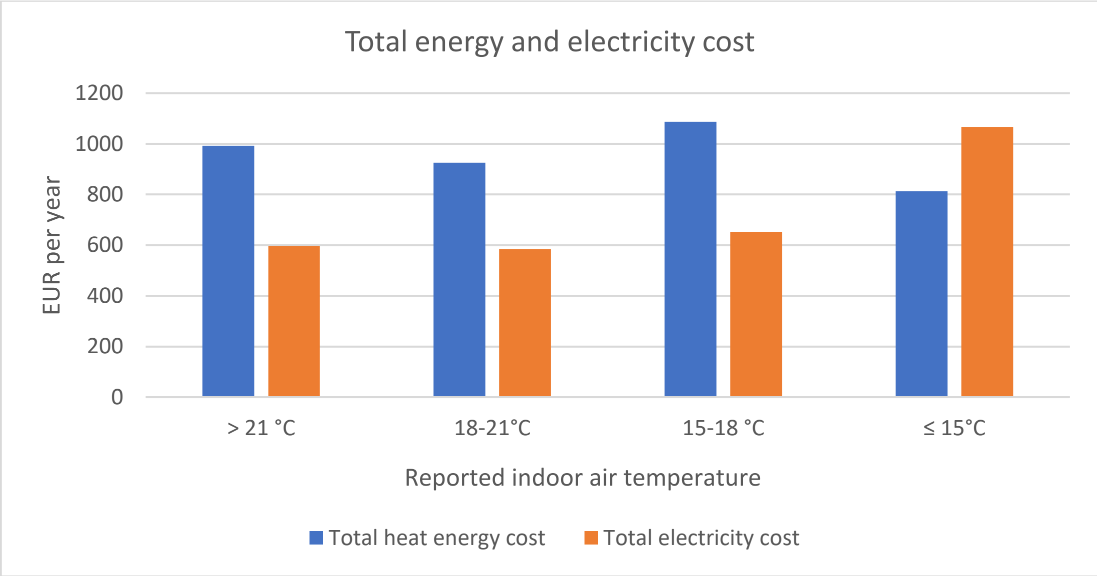


Figure 97. Total annual energy and electricity costs by house temperature in winter

Energy expenses are also affected by households' characteristics. As shown in Figure 98, the higher the number of household members the higher the energy costs. However, this increase is declining. From a one-member to a two-member household the increase is, on average, 27.3%, from a two-member to a three-member household is 6.8%, from a three-member to a four-member household is 5.8% and from a four-member household to a household with five or more members is 2.6%.

Furthermore, households with children less than 7 years old tend to spend more to meet their energy needs. On the opposite side, households with pensioners, family members with disability or long-term sickness or unemployed persons tend to spend less (Figure 99).

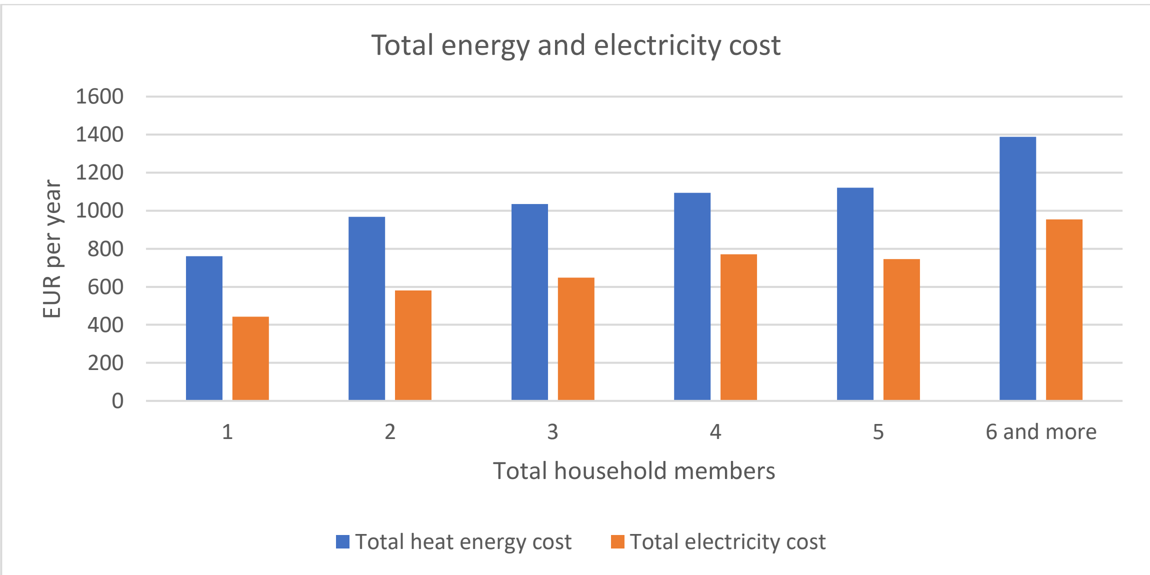


Figure 98. Total annual energy and electricity costs by total household members

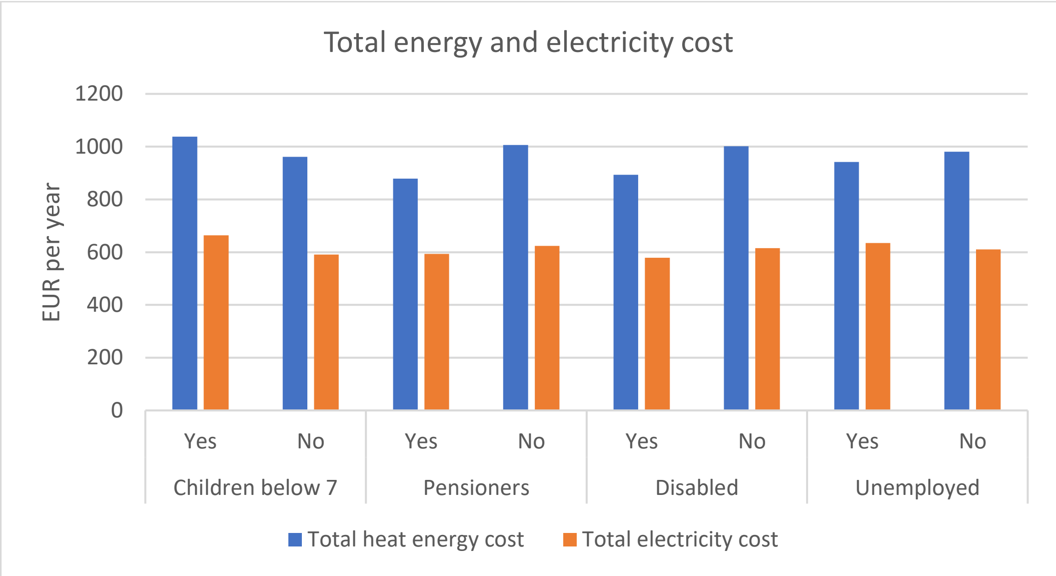


Figure 99. Total annual energy and electricity costs by specific household characteristics

Finally, there is no clear distinction in energy cost trends between reported household income level and energy costs (Figure 100). The difference is relatively small (around 100-150 euros per year), suggesting that energy is an inelastic good.

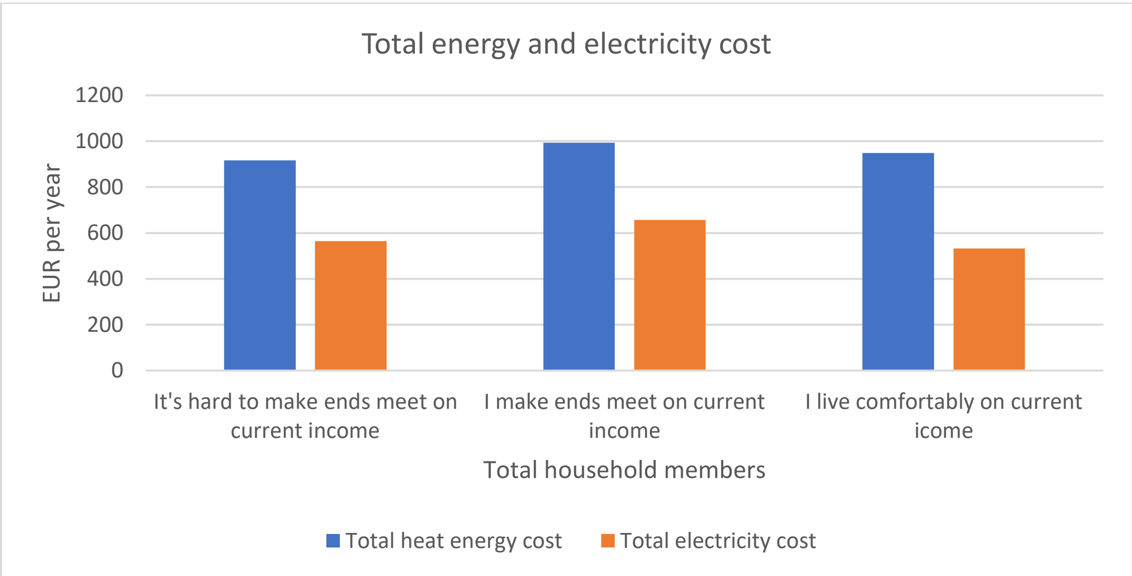


Figure 100. Total annual energy and electricity costs by self-declared income adequacy

3.6 Energy efficiency interventions and awareness

The survey explored issues related to implementation of energy-saving measures, participation in energy saving subsidy programmes, awareness about such programmes, etc.

As presented in Table 20, about half of the households have installed energy efficient windows and doors and energy saving lamps, one-fourth have upgraded household appliances to more efficient ones. About 10% have insulated the walls, floors, and ceiling of their houses and have upgraded the heating system. Only 6.3% of the respondents report that their multifamily building has undertaken deep renovation. And only 0.2% report installing PV panels, which is expected as installation of PV panels is not yet legally sorted in multifamily buildings. This is expected to be done when definition and mechanisms for energy neighbourhoods are established. The responses corelate with Ekodoma's observations during energy auditing of multifamily buildings. The most popular energy saving measures in multifamily buildings are those which can be implemented in individual apartments. In order to implement major energy efficiency measures, it is necessary for the majority of the apartment owners in a multifamily building to vote on a specific measure or undergo a deep renovation. Sometimes, exterior walls are also insulated from the inside of the apartment, as exterior insulation of building envelope is allowed only when the whole building is insulated.

Table 20. Implemented energy efficiency measures in the past 10 years

	Energy efficient windows and doors	Wall/ceiling insulation	Deep renovation of the building	Upgraded heating system	New energy efficient appliances	Photovoltaics on the roof	Energy-saving lamps
Yes	*51.7%*	*11.2%*	*6.3%*	*10.3%*	*24.5%*	*0.2%*	*45.4%*
No	*47.9%*	*88.3%*	*93.3%*	*89.2%*	*75.1%*	*99.3%*	*54.2%*
I don't know/No answer	*0.4%*	*0.4%*	*0.4%*	*0.4%*	*0.4%*	*0.4%*	*0.4%*

About one-tenth of the households have participated in subsidy programmes (Figure 101).

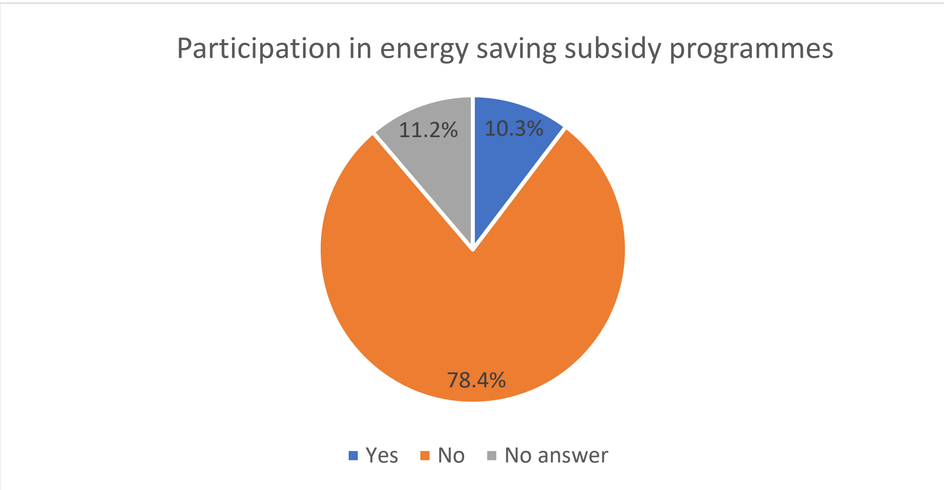


Figure 101. Participation in energy saving subsidy schemes

The five most important reasons (in terms of importance) for not having participated in subsidy programmes are presented in Table 21. Leaving aside those who live in a relatively new and of a good energy class house, the rest of the responses reveal a number of barriers. The most important barrier, which was mentioned by 30.5% was the inability of apartment owners to apply for a building renovation subsidy. Another indicated problem was the high bureaucratical burden, which was mentioned as having second and third important reason. Relatively high percentage of respondents indicated that they don't think that there would be large enough energy savings to substantially affect their energy bills – 14.8 and 15.7% of people have mentioned this as third and fourth most important reason accordingly. It seems also that people are reluctant to take on any action as 13.9% an 13% have indicated as their third and fifth most important reason that nobody in their building has raised the question of building renovation through subsidy programme. The subsidy programs of building renovations do not cover all the necessary costs for building renovation, therefore the inability to repay the additional renovation costs was mentioned as most important factor in 11.2% and 14.8% as fifth important reason.

Table 21. Reasons for not having participated in subsidy programmes

Reasons for not participating	**First most important reason**	**Second most important reason**	**Third most important reason**	**Fourth most important reason**	**Fifth most important reason**
I couldn't afford it, the loan payment was expected too high	11.2%	7.0%	9.3%	6.0%	14.8%
I didn't know there were such subsidy programs	7.1%	5.3%	4.6%	9.6%	7.8%
I was afraid of bureaucracy	11.7%	18.4%	20.4%	7.2%	13.9%
There were issues with the ownership of the house	2.0%	5.3%	3.7%	8.4%	4.3%
Apartment owners could not agree to participate in subsidy program	30.5%	17.5%	8.3%	12.0%	13.9%
There was no trust in information provided by the building maintenance company	4.6%	3.5%	6.5%	9.6%	5.2%
The subsidy was expected too low and the investment in building renovation didn't pay off	3.0%	8.8%	5.6%	7.2%	4.3%
The walls of the building are thick enough, therefore it is not necessary to add additional insulation layer	3.6%	6.1%	1.9%	4.8%	3.5%
I could not get a loan from bank	1.0%	0.9%	2.8%	0.0%	0.9%
My home is relatively new and of a good energy class	6.6%	3.5%	3.7%	1.2%	1.7%
I don't think my energy costs will be significantly reduced	6.1%	8.8%	14.8%	15.7%	6.1%
I think that building wall insulation causes mould growth and other problems	3.0%	4.4%	1.9%	9.6%	5.2%
It is not possible to renovate my building	0.5%	2.6%	1.9%	1.2%	3.5%
Nobody in our building has come up with an initiative to renovate our building	8.1%	7.9%	13.9%	7.2%	13.0%
Other	1.0%	0.0%	0.9%	0.0%	1.7%

As far as information about subsidy programmes is concerned, participants seem to adopt a passive attitude, believing that municipalities should inform households about existing possibilities to finance energy saving actions (Figure 102). This finding highlights the importance of one-stop shops in encouraging households to engage in such programmes.

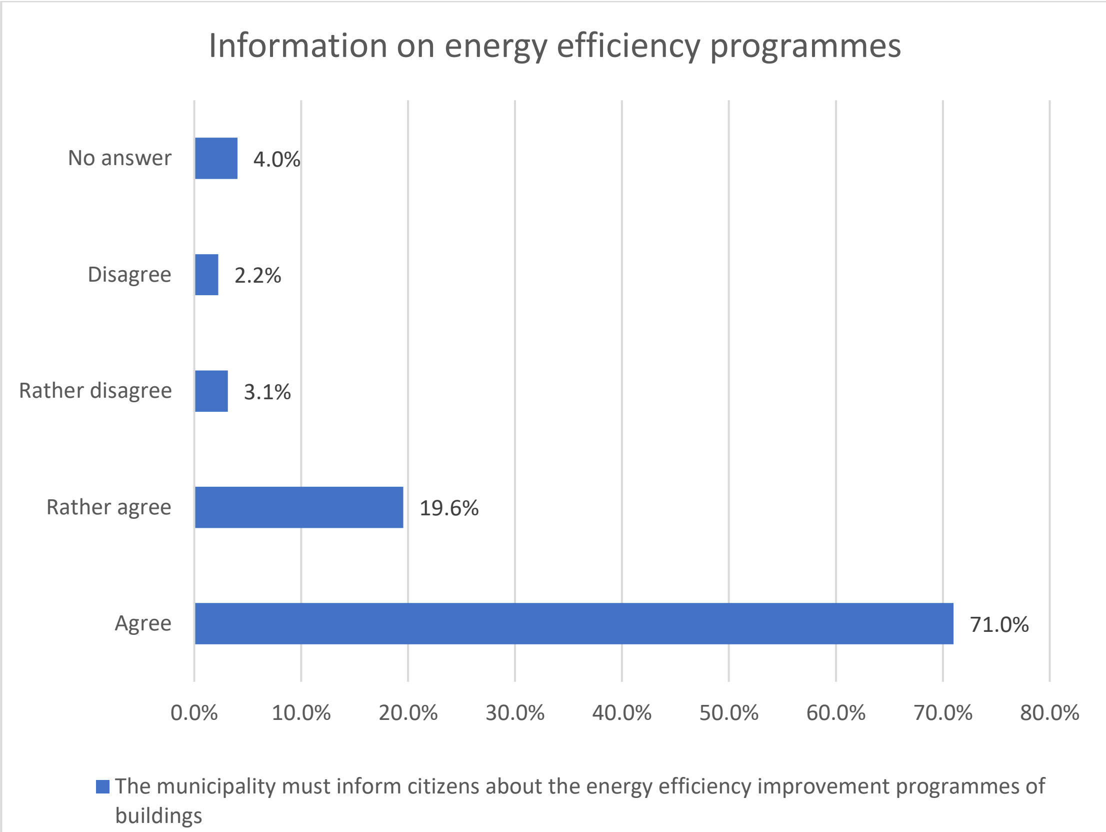


Figure 102. Information on energy efficiency programmes

3.7 Energy poverty, vulnerability and behavioural perspectives

Towards assessing energy vulnerability in Riga, several expenditure-based and consensual indicators were calculated from the survey, as follows:

1. Condensation on windows and walls during winter
2. Inability to keep home adequately warm
3. Arrears in energy bills over the last 12 months
4. Electricity/gas supply disconnections in the last 12 months
5. Health problems due to inadequate heating or moisture
6. A composite consensual indicator calculated as follows:

   Composite indicator = Health problems*0.25 + Inability to keep house warm*0.25 + Electricity/gas disconnections*0,25 + Arrears in bills*0.15 + Condensation*0.10

This indicator receives values from 0 to 1; energy poor households are those having value greater than 0.5.

7. The 'Ten-Percent-Rule'
8. A 'local' 2M indicator (i.e., based on median energy expenditure of the sample)
9. A 'local M/2 (i.e., based on median energy expenditure of the sample)

In addition, cutbacks on essential spending by households (e.g., food, medicines, electricity, heating, hot water, kids' education) were investigated to identify those who are energy poor and, at the same time, are forced to cut back on essential goods.

3.7.1 Consensual indicators

As far as the consensual indicators are concerned (Figure 103), the main findings are the following:

- About 41.8% of surveyed households claim inability to keep their houses adequately warm in winter. These percentages exceed 49.3% in households with a monthly income of less than around €900.
- One-fifth of the households report condensation on windows and walls during winter. These percentages about the same in households with a monthly income of less than about €900, which means that this may not be a significant factor.
- Only about 4% report arrears on their energy bills and none of the respondents said that their electricity/gas supply was disconnected during the last 12 months. These percentages are relatively low and maintain low also for households with a monthly income of less than around €900, also 4%.
- About one-fifth of the households (21.6%) report health issues related to inadequate heating and/or the presence of high moisture in the house. Low-income households appear more vulnerable to these problems. For example, the percentages are 33.3% for households with a monthly income below €900.
- As mentioned, a composite EP measure was also developed by the consensual indicators. According to this indicator, the energy poor households (i.e., those having a value above 0.5) are 9.2%. Households with a monthly income below €900 are classified as energy poor at 14.7%.

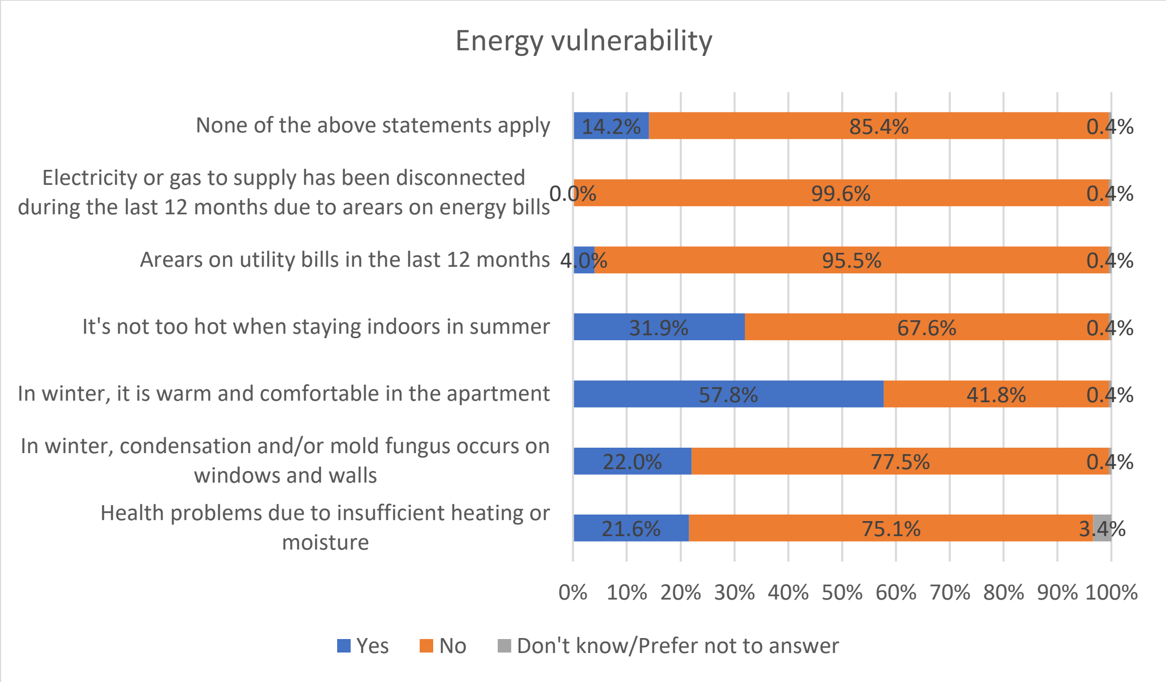


Figure 103. Consensual indicators of energy vulnerability

Moreover, since energy-poor people usually restrict their basic needs (such as food, medicines, etc.) to make ends meet, cutbacks on essential spending by households were investigated. As shown in Figure 104, about 42.2% of the households have restricted the use of electricity, more than 18.7% the use of heating, and about 37.8% the use of DHW in order to be able to pay for energy use during the last 12 months. Moreover, one third report cutbacks on food purchases, and 22.5% mention cutbacks on transportation. Not surprisingly, more 'inelastic' goods, such as medicines or expenses related to kid's education show smaller spending cuts, whereas less necessary goods (e.g., entertainment, clothing, etc.) show higher spending cuts.

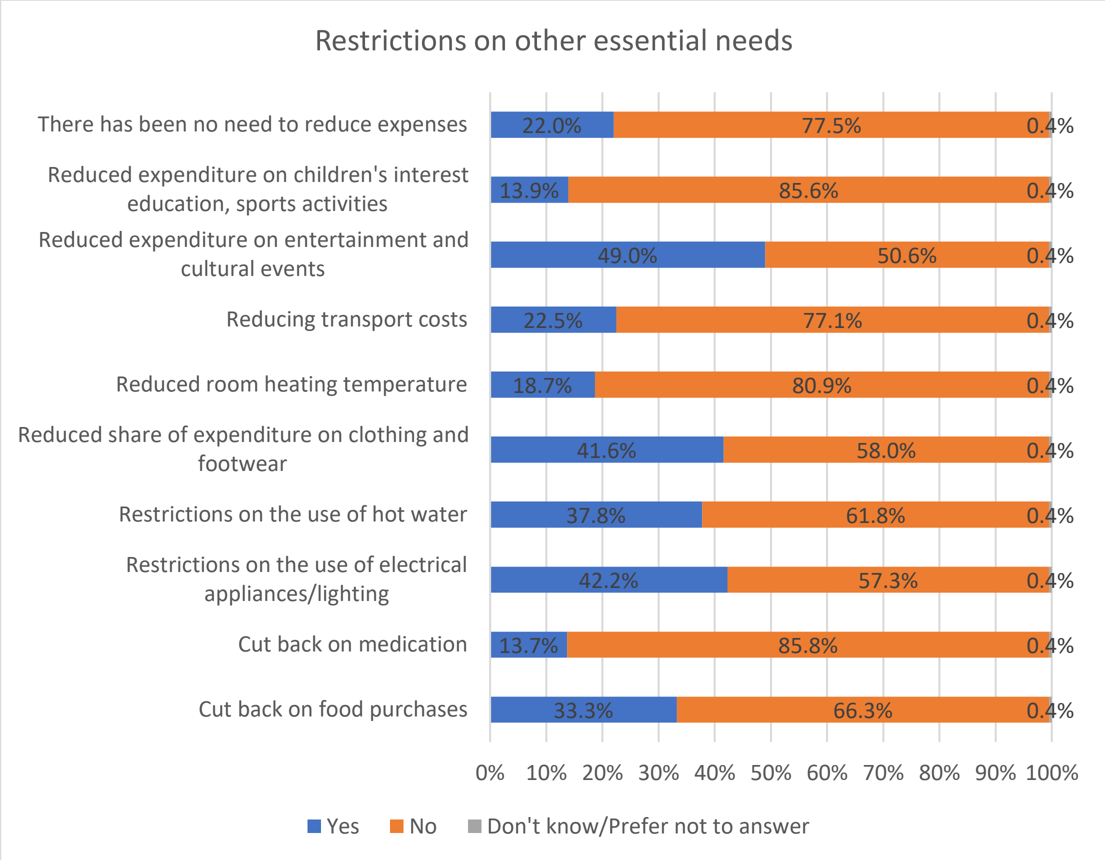


Figure 104. Restrictions of other essential needs in order to pay for energy, over the last 12 months

Table 22 shows the percentage of households that are in the hardest position, i.e., are energy poor (according to consensual indicators) and at the same time are forced to cut expenditure on basic goods. By cutting back on basic goods it is still not possible to keep a home adequately warm and prevent condensation and mould growth. There is a high discipline on utility bill payments, although there are arrears on bills none have experienced cut off in energy delivery.

Table 22. Percentage of households that have restricted other essential needs to pay for energy use and are characterised as energy poor (consensual indicators)

	Health problems	Condensation /Mould	Inadequate warm house	Arrears in bills	Electricity/ gas disconnections
Cut back on food purchases	100%	100%	0%	17%	0%
Cut back on medicines	100%	100%	0%	19%	0%
Cut back on hot water	100%	100%	0%	9%	0%
Cut back on children’s education	100%	100%	0%	11%	0%
Cut back on transportation	100%	100%	0%	23%	0%

3.7.2 Expenditure-based indicators

According to the 'Ten-Percent-Rule' (TPR), about 37.0% of the surveyed households are characterised as energy poor, i.e., they spend more than ten percent of their net income on energy services.

As an alternative option to capture the burden that energy bills put on households relative to their disposable income, the 2M indicator, which represents the proportion of households whose share of (equivalised) energy expenditure compared to (equivalised) disposable income is more than twice the national median, was used. These indicators were estimated at a 'local' level, i.e., using energy expenditure and income data from the survey, to allow comparisons with other indicators calculated by the survey. The 'local' 2M and M/2 indicators are equal to 9.3% and 10.1%, respectively.

As shown in Figure 105, no clear trend is emerging from the analysis of reported income and respective calculated energy poverty indicators. One clear trend, which is observed, is that in households with very low income, there is a strong mark of underconsumption of energy.

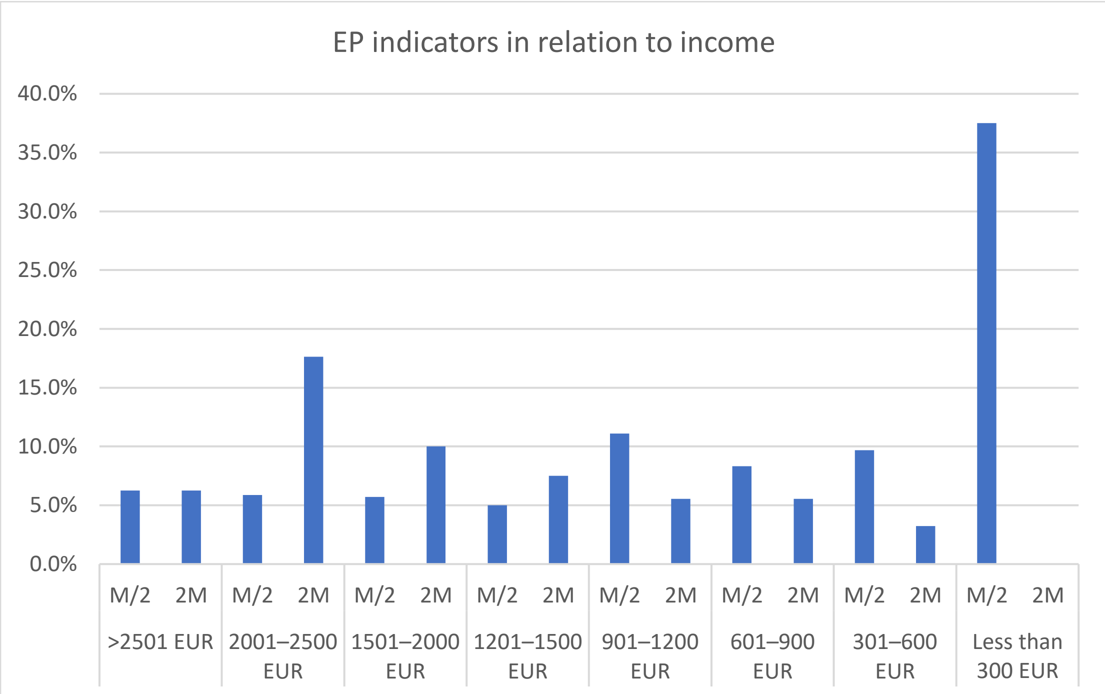


Figure 105. Expenditure-based EP indicators in relation with income

Table 23 presents the percentage of households in the hardest position, i.e., those who are categorised as energy poor based on the expenditure-based indicators and forced to restrict essential needs.

Table 23. Percentage of households that have restricted other essential needs to pay for energy use and are characterised as energy poor (expenditure-based indicators)

	10% rule	2M	M/2
Cut back on food purchases	26.0%	52.8%	23.1%
Cut back on medicines	7.7%	25.0%	10.3%
Cut back on children's education costs	34.2%	50.0%	38.5%
Cut back on transportation	29.6%	44.4%	41.0%
Restriction on the use of the heating of the house	14.3%	30.6%	25.6%
Restriction on the use of electrical appliances/ lighting	18.4%	36.1%	17.9%
Restriction on the use of hot water	8.7%	30.6%	7.7%

As mentioned in the literature, each expenditure-based EP indicator measures a different aspect of the problem. For example, as mentioned, the M/2 indicator aims to capture the 'hidden' energy poverty, i.e., households that underconsume energy services, while the 2M indicator aims to capture the excess burden that energy bills put on households relative to their income.

3.7.3 Social support and perceptions

Surveyed households believe that the State should support households unable to pay for their energy needs mainly through energy renovation programmes (84%) and secondarily through vouchers, fuel rebates, energy price allowances, etc. (78,9%) (Figure 106). This is particularly useful evidence from an energy policymaking perspective, as it highlights the social preference for energy saving measures as opposed to views that argue that households prefer support to cover their energy needs through subsidies. However, the results are rather close, therefore in case of households in the most difficult circumstances, additional support is necessary. Finally, respondents believe that energy providers do not support vulnerable households as much as they could. In particular, 72% of them consider that energy providers do not treat low-income consumers fairly.

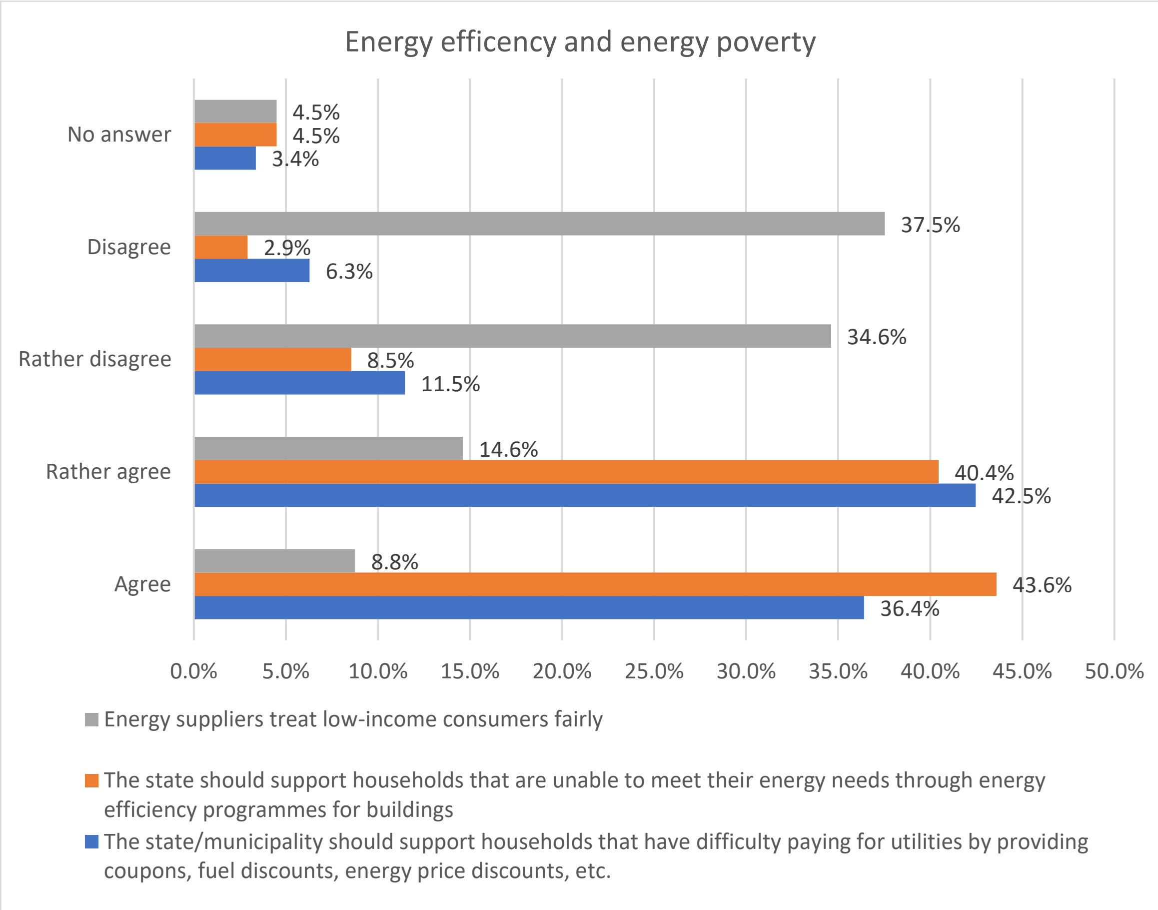


Figure 106. Beliefs about State support measures

4 Pilot 4 - Coimbra (Portugal)

4.1 Survey administration

In Portugal, the first concern was to ensure the accomplishment of GDPR rules. ISR has consulted with the GDPR responsible for the University of Coimbra, being shared the REVERTER privacy policy. The GDPR officer of the University of Coimbra validated REVERTER proposal for Privacy Policy through the lenses of its own data protection rules. He advised us to also consult with the GDPR officer of the Municipality of Coimbra – what we did - because the survey was to be launched simultaneously by the two Portuguese entities and the application of the rules, in the spirit of the legislator, could differ between the two institutions. Moreover, individualized practices for processing personal data cannot be generalised and both Institutions have to agree on the procedure. Having heard from both officers, we come up with the following rules to avoid any breach of GDPR norms:

Online survey

1. For the dissemination of the survey, ISR/CMC will have to use lawful vehicles. A network of informal contacts or social networks will be the easiest. In case the use of institutional mailing list is used, the purpose of these lists will have to be analysed in advance. In the case of using the UC institutional lists, the UC GDPR Officer has to give his opinion and then superior authorization. The Municipality follows a similar procedure.
2. Free of charge platforms like Google Forms or Survey Monkey, are not eligible because they are not GDPR compliant. The University suggested using LimeSurvey, which the University is authorized to use free of charge, and the surveys and the data storage are kept in our own survey.
    a. LimeSurvey is an open-source survey platform that our University server hosts. It gives us complete control over data storage and compliance. With proper configuration and security measures, LimeSurvey can ensure GDPR compliance for our Social Survey.

Paper-based survey

3. Data processing carried out by a natural person in the exercise of exclusively personal or domestic activities is outside the GDPR. However, if processing involves personal data informed consent / legal information is required (which is not the case in REVERTER social survey);
4. REVERTER "privacy statement", is generic but is excellent for preceding a collection of personal data. If there is a need to collect personal data directly, there is a need to inform our respondents about art. 13 of the RGPD.

Therefore, considering this legal aspect, and having the commitment to collect 300 valid questionnaires, the dissemination strategy of the questionnaire in Portugal was agreed to be done in several ways to be more successful, including some interviews based on the paper questionnaire:

- Online format, using LIMESURVEY platform, that is GDPR compliant, to advertise on social networks and through CMC and ISR website;

- Online format by sending email to CMC and UC staff;
- Online format for emailing to our contact networks;
- Online format, by asking our associates to distribute the questionnaire in order to cover different regions of the country;
- Online format for dissemination among CMC users who live in and need social housing; This can be filled in with CMC assistants during the regular attendance to these situations;
- Online and/or paper format to be distributed to the parents of school age students, in the scope of the management of the schools under CMC's responsibility.

Besides the link to enter the survey (https://ls.uc.pt/index.php/279318?lang=pt) we provided a brief description of the project and an explanation about the importance of this social survey. For those contacted by email, a pdf version of the survey was provided when respondents prefer to see the overall survey before starting to complete.

Timing survey: The survey was open from May 2023, as expected, to end August 2023, a bit later than it was predicted. There were two main reasons for the delay in running the survey: on one hand, by mid-May, there were some constraints with the implementation of the Social Survey in Lime. The University servers hosting the Lime Platform were out of order for two weeks and all the services provided were down. The server broke down and had to be replaced by new hardware. Then, it took time to restore and upload all the information into the new server. This problem was out of our control, and to be GDPR compliant, there was no other option for implementing the online survey. On the other side, the response rate was not as high as expected and the closing was postponed to the end of August.

Continuous control of the collection of replies: To avoid the risk of non-fulfillment, ISR has been controlling the collection of replies frequently, downloading the xls file every week with the replies for check completion rate, level of quality of answers and the total number of responses, thus enabling to change and or adapt the strategy for dissemination (for example, the social workers of the Municipality have been visiting several households to fill in the questionnaires; personal emails have been sent to friends of friends; reminders when needed, etc.).

In total, 462 people followed the survey link they received from either a personal email or were informed via websites and social networks, and 330 people provided valid answers. Among these, 127 replies were not valid, 260 replies were fully complete and 70 were not fully complete yet are valid replies. The high number of invalid questionnaires seems to be related to people entering the link through social networks, like Facebook. They started to fill in the questionnaire but gave up already on the second question which was related to the building envelope. Among the ones that fill in the full questionnaire, there are some comments about the questionnaire being too long and not simple to understand.

4.2 Demographics

A total of 299 answers were valid to be included in the analysis of the socioeconomic and demographic characteristics which are presented in
Table 24. Surprisingly, or not, the survey attracted a larger number of males, representing 45.5% against 32,4% females. Regarding the education level, 52% of the households answering have a

university degree, mainly from technical areas, which represent 35.9 percent of the households. In total, 146 respondents have a University degree in a technical area, being 92 males and 54 women. We can assume that these numbers provide some evidence about the impact of background education towards engaging in energy related issues, and what is related to the power of education regarding citizens' empowerment and engagement.

In relation to the number of members per household, most households include two persons (32.1%), 2.,4% are formed by three persons, 15.7% with four persons, 11.7% single family, 5% with five persons and only 1.3% with six persons. In the total sample, 6% of respondents did not provide this information.

Table 24. Socioeconomic and demographic characteristics

	Attributes	**N**	**%**
Gender	Female	97	32.4
	Male	136	45.5
	prefer not to answer	66	22.1
Household Members	1	35	11.7
	2	96	32.1
	3	85	28.4
	4	47	15.7
	5	15	5.0
	6	4	1.3
	No response	17	5.7
HH with children	1	38	12.7
	2 or more	47	15.7
HH with students	1	82	27.4
	2	122	40.8
	3	26	8.7
	More than 3	38	12.7
HH with Pensioners	1	40	13.4
	2	17	5.7
	More than 2	1	0.3
Full time employed household members	1	87	29.1
	2	139	46.5
	3	8	2.7
	More than 3	1	0.3
Unemployed	1	25	8.4
	2	1	0.3
	3	0	0
	More than 3	0	0
Education level	Graduated (technical area)	270	35.9
	Graduated (humanities)	121	16.1
	Secondary school	100	13.3
	Secondary vocational	23	3.1
	Elementary school	58	7.7
	primary school	84	11.2
	Kindergarten	90	12.0
	Prefer not to answer	7	0.9

Regarding the employment status of the members of the household, the rate of employment is quite high. About half (46,5%) of the households have two members working full time on a regular basis, 29% and 2,7% have one and three members, respectively, also working full time. Only 8.4% of the households have one member who is unemployed.

Table 25 presents the net monthly income and Table 26 the monthly HH expenditure.

Table 25. Net monthly income

Net monthly income	N	%
up to 300	11	3.7
301-600	14	4.7
601-900	41	13.7
901-1200	22	7.4
1201-1500	35	11.7
1501-2000	35	11.7
2001-2500	45	15.1
>2500 euros	59	19.7
Prefer not to answer	25	8.4
empty	12	4.0

Table 26. Monthly HH expenditure

Monthly HH expenditure	N	%
up to 500€	37	12.4
500-1000	89	29.8
1001-2000	95	31.8
>2001	47	15.7
Prefer not to answer	31	10.4

Table 27 and Figure 107 show that a significant part of the sample, 57% of the households who did reply, spent more than 50% of their income, and 22% do not provide a reply to this question.

Table 27. Expenditure to net income

Expenditure to net income	N	%
Less than 30%	6	2.0
30%-50%	56	18.8
50%-70%	54	18.1
70%-85%	31	10.4
85%-100%	45	15.1
over 100%	40	13.4
No response	66	22.1

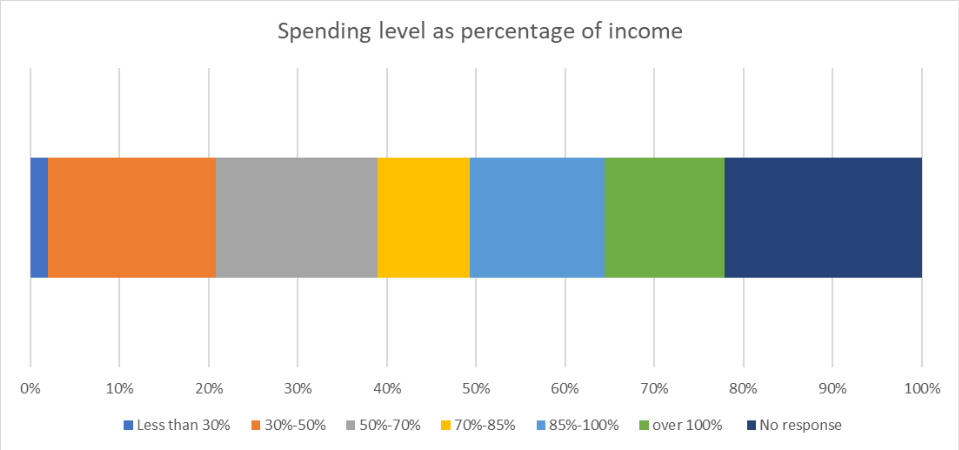


Figure 107. Spending level as percentage of income

Figure 108 shows the relatively low level of economic empowerment of our sample. If we consider the share of graduated people in the sample is significant, and are considered an average class in Portugal, it is not inappropriate to state lay people are struggling hard to comply with their expenses.

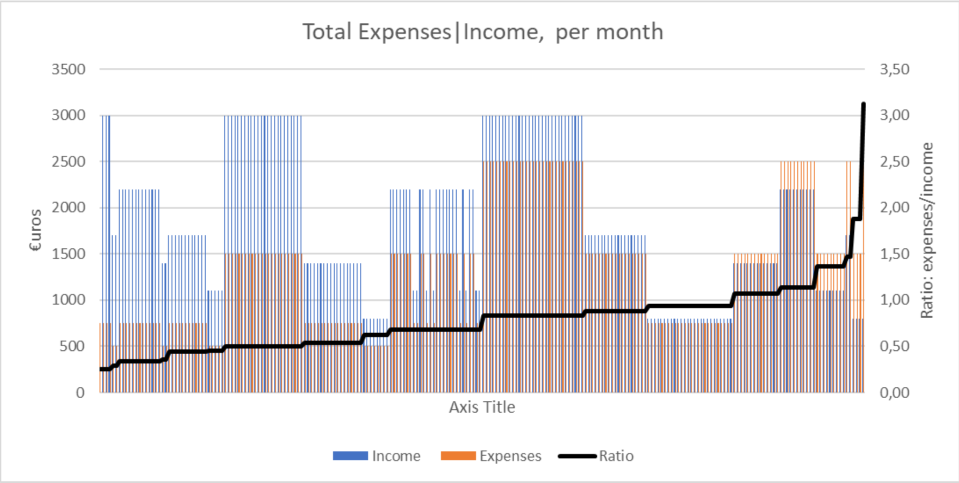


Figure 108. Total expenses and income per month

As can be seen, the share of the population for which the ratio of Expenses/Income is above 1 is significant; Over 30% of respondents spent more than 85% of their income, and for 17% of the households, the available income is not even enough to cover monthly expenses. Assuming there is naturally some embarrassment in admitting this fact, we can deduce that this percentage is most probably higher, and the situation should be even more dramatic.

When asked how they describe their current income to face the expenses, HH were asked to select one option that better matched their own situations. The results are presented in Figure

109. As can be seen, the percentage of respondents who admit living comfortably on current income is not significant.

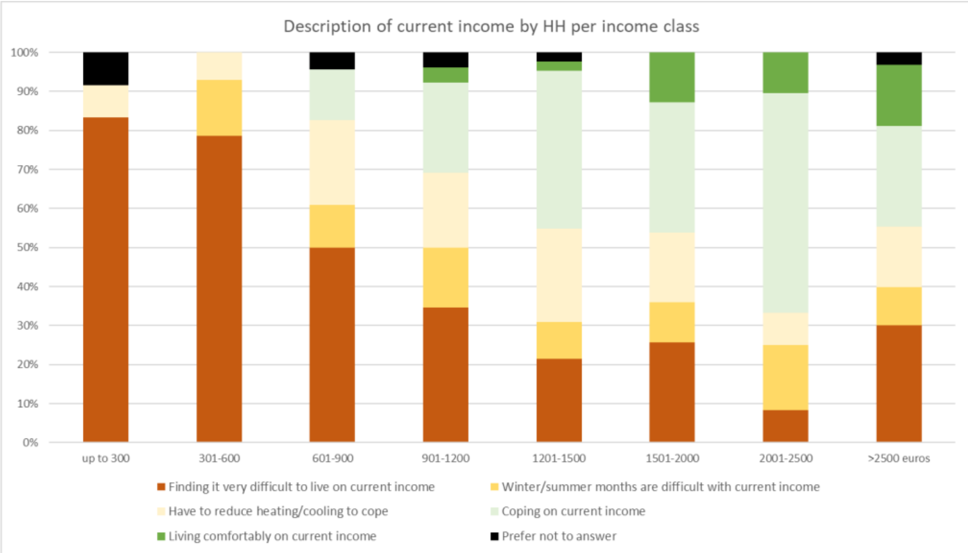


Figure 109. Description of current income by HH per income class

The lowest income classes represent the group with the higher number of no replies, in this question. This is not surprising. Many authors already identified and addressed similar findings and explain that this is related to the feeling of embarrassment preferring not to answer. In REVERTER, when the home visits are carried out, we will try to figure out how this is in reality and validate our survey.

4.3 Housing characteristics

As can be seen in Figure 110, most houses were built between 1960-2010, built on concrete structures and low insulation. The second largest share of houses were built after 2010, with newer regulations and after the first thermal building code was introduced in Portugal. As presented in Figure 111 the most common type is apartments.

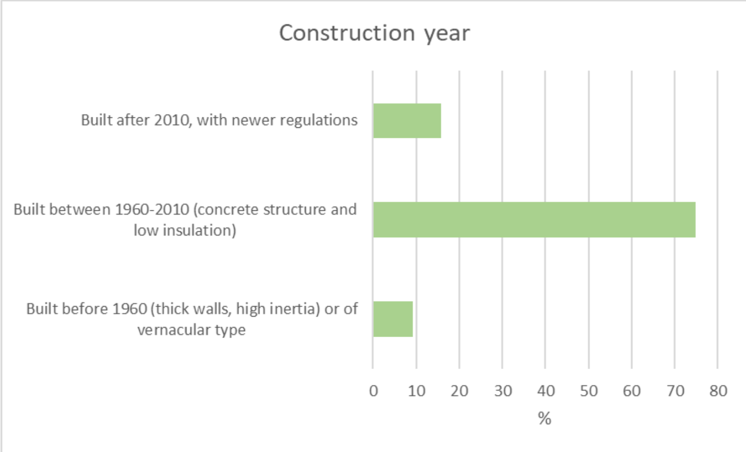


Figure 110. Construction year

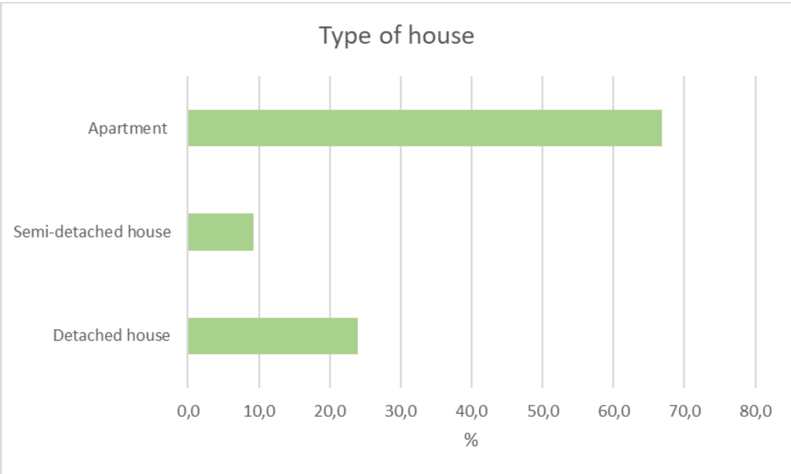


Figure 111. Type of house

When looking at the average floor areas (Table 28), per period of construction, it is not possible to provide any conclusions. However, if we look at the min, max and median in each category, it is possible to come up with an interesting chart (Figure 112) that shows a slight tendency to increase in the area of houses in Portugal. As presented in Figure 113 most buildings have 2 or 3 rooms.

Table 28. Average floor areas (in m^2)

	max	min	average
Built before 1960 (thick walls, high inertia) or of vernacular type	300	51,0	135,9
Built between 1960-2010 (concrete structure and low insulation)	600	30,0	135,5
Built after 2010, with newer regulations	300	85,0	153,3

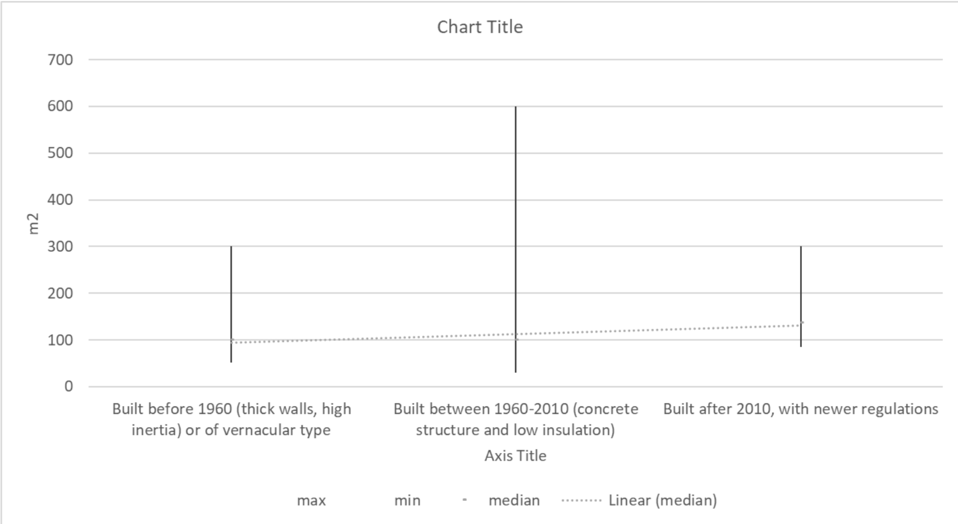


Figure 112. Average floor areas (in m^2)

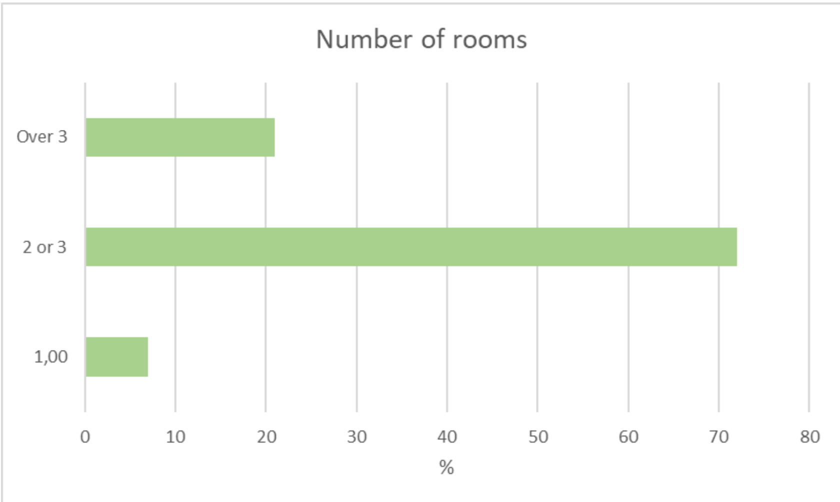


Figure 113. Number of rooms

When asked about the characteristics that influence their need/possibility to intervene, the households were faced with a set of questions grouped into 5 specific clusters, tenure of house, self-declared comfort, mode of ventilation being used, conservation of the house in terms of humidity, mould, and draughts. There was also a question about the habits with opening the windows, doors and other openings.

Respondents were asked about the characteristics of their property, in regard to the ownership status of the property, being presented with several options that could influence their need and or possibility to intervene. Only 26% of respondents own their house without financial obligations, among which, 10 respondents indicated their decision must be validated by a condominium (Figure 114).

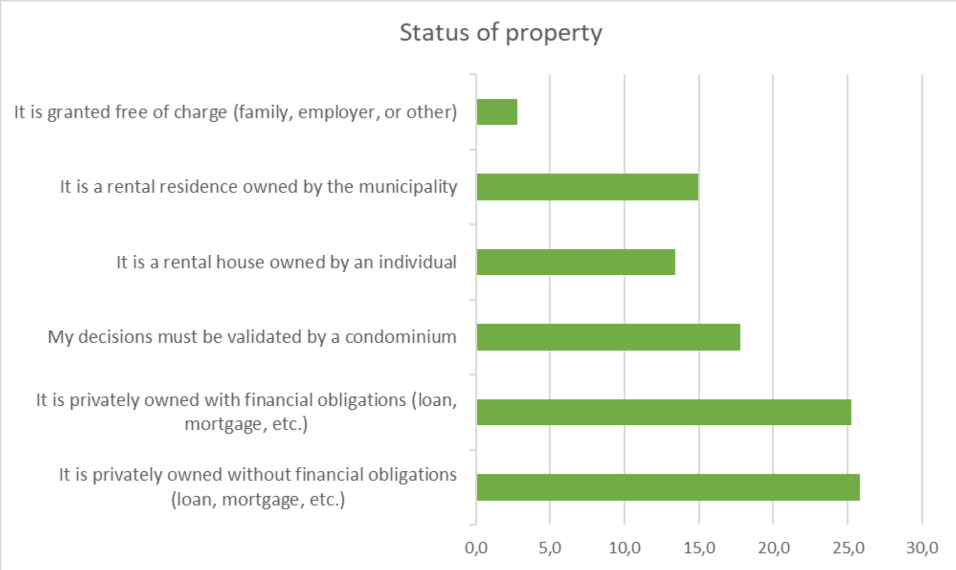


Figure 114. Status of property

Only six persons selected two answers in relation to self-declared comfort, reinforcing the discomfort in winter.

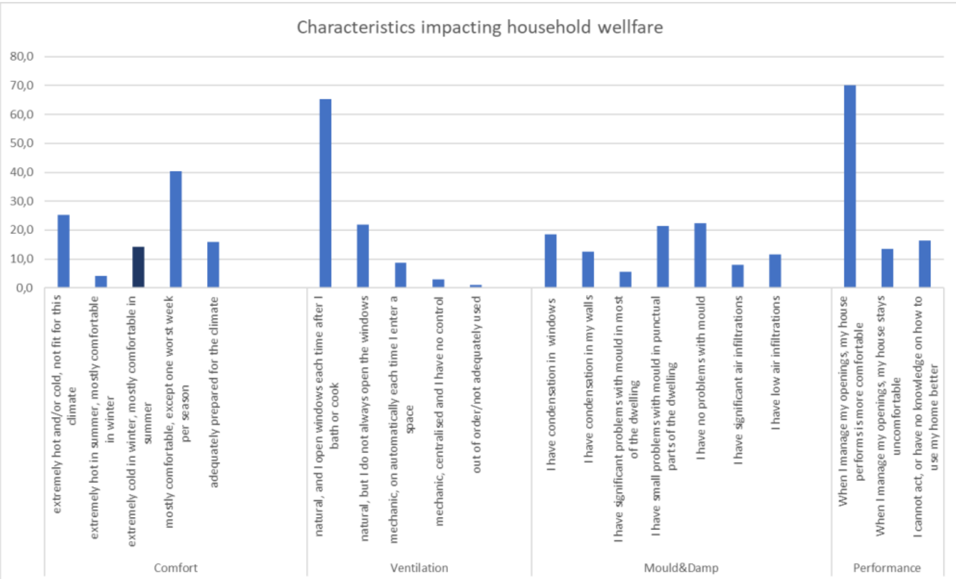


Figure 115. Characteristics impacting household welfare

It can be seen in Figure 116, that even for a relatively short sample of 300 hh, houses built between 1960 and 2010, previous to the first thermal building code adopted in Portugal, use a larger amount of energy. Furthermore, it is also evident that older houses, built with thick walls and high inertia, also have a better performance. Of course, this should be taken with caution because the number of houses in these two categories is also smaller. Nevertheless, these analyses show clearly there is a direct relationship between the energy bill and the envelope of the building.

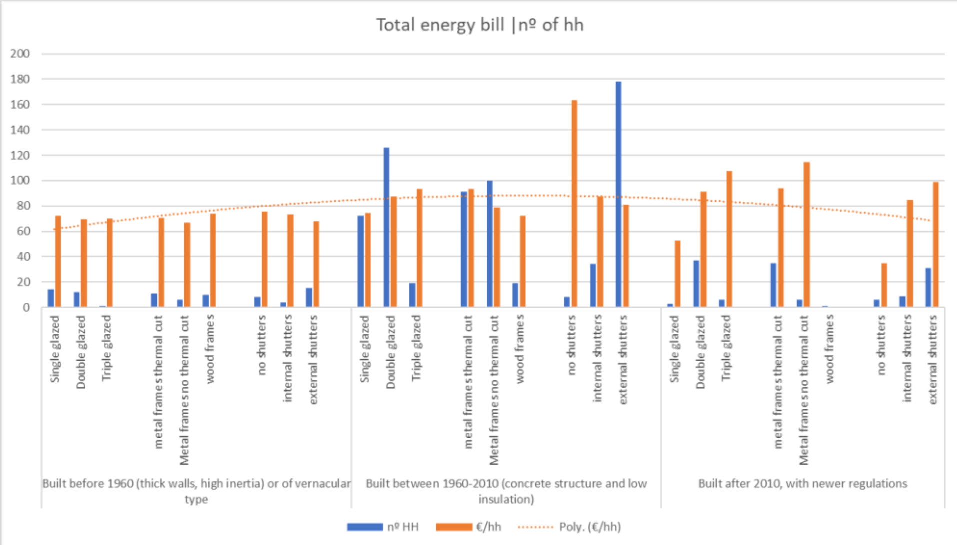


Figure 116. Total energy bill

4.4 Mechanical systems

If the self-declaration of the comfort perceived is compared with the main heating system being used (Figure 117), it is possible to see, without surprise, that radiant floor and central system are the solutions that provide the best comfort. It is also interesting to see that those households indicating less comfort issues at home have solar PV and solar thermal installed (Figure 118).

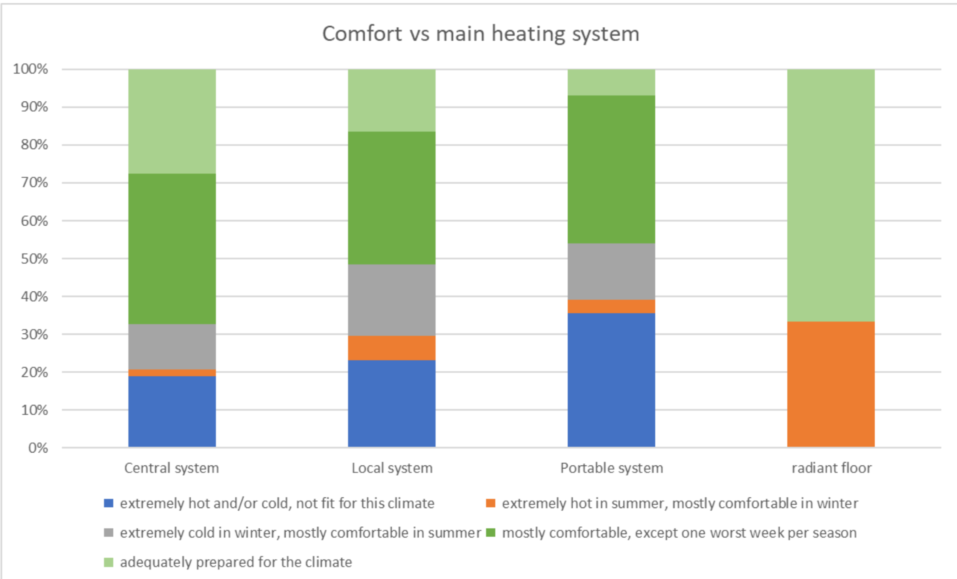


Figure 117. Comfort and main heating system

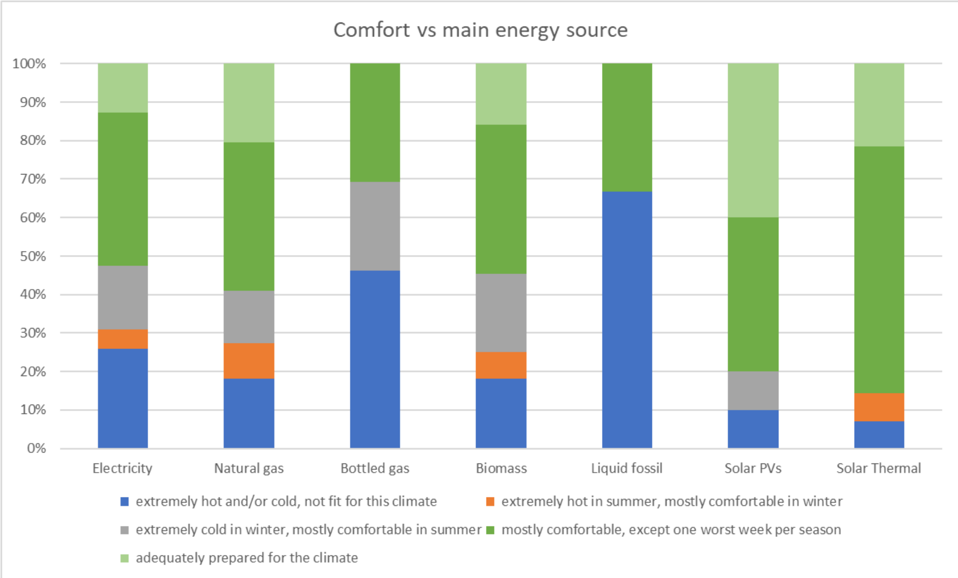


Figure 118. Comfort and main energy source

Regarding cooling (Figure 119), about 43% of households indicate to have some kind of air conditioning system, mostly local systems: about 60% of households have one equipment for mostly one room, central systems are only available in 17% of the households and 2304% use a portable system for meeting their cooling needs (portable ACs, portable heat pumps, etc.).

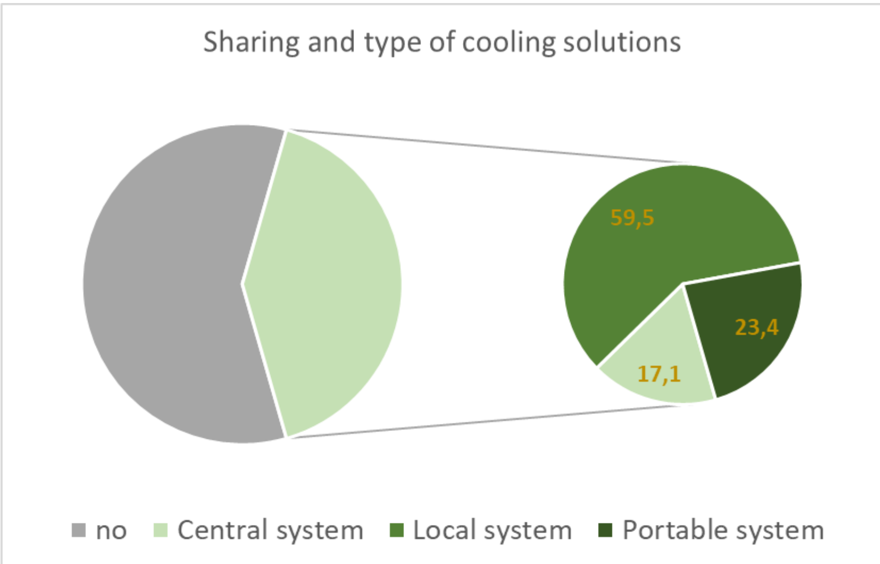


Figure 119. Sharing and type of cooling solutions

4.5 Energy costs and habits

When asked about heating and cooling habits, households have the possibility to choose the best fitting answers from different groups, from the number of rooms being heated, and cooled, for how long, and within each set point temperatures, both in winter and in summertime (Figure 120).

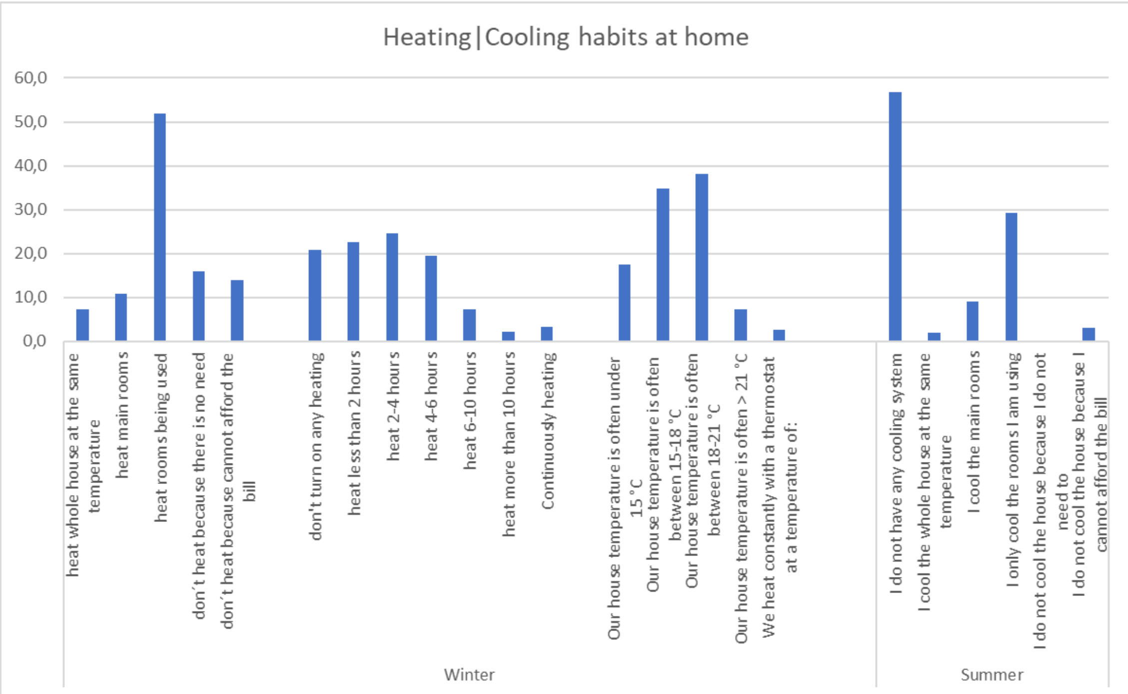


Figure 120. Heating and cooling habits

About 60 percent (56.8%) of our sample do not have any cooling system. The average ownership rate of air conditioning in Portugal is estimated at around 21% according to a recent survey[12]. Other studies state that air conditioning has been increasing in the last decade, from 16.2% in 2013 to 21.8% in 2020[13]. Although there are no official statistics on the ownership rate, the numbers are significantly lower than our sample survey with a penetration rate of 43%. This can be explained by the relatively high percentage of educated people, with university degrees, within our sample. It is logical to assume this segment of society has better economic power purchase explaining this difference.

The market studies also indicate there is a big difference in the penetration of this equipment according to the related region. For those surveyed in the South, the figures are 73% higher than the national average. There are also significant differences between social classes, with the figures falling from 29.6% among the highest income to 17.7% among the lowest income.

Another important limitation is the "denial of reality bias" that many researchers point out. Energy-poor people might deny seeing themselves as being in an uncomfortable situation and, therefore, do not declare it (only 8 respondents admitted not cooling the house because they

---

12 IDEALISTA, 2021: Casas com ar condicionado em Portugal — idealista/news. Accessed October 2023.

13 Marketest 2021, Aumenta posse de ar condicionado no lar : Notícia (marktest.com). Accessed October 2023

cannot afford the bill!). This analysis must be taken with caution and there is a need to cross indicators to get an overall and comprehensive picture of the situation. The survey confirmed energy poor does not only occur in winter, as the researchers have been stressing; the inability to cool a household during the summer months can be inferred from Figure 121. The majority (56.8%) do not have any air conditioning, and when air conditioning is available, they indicate a low utilization rate (about 30% only cool the rooms being used and 9% only cool the main rooms) as Figure 121 shows.

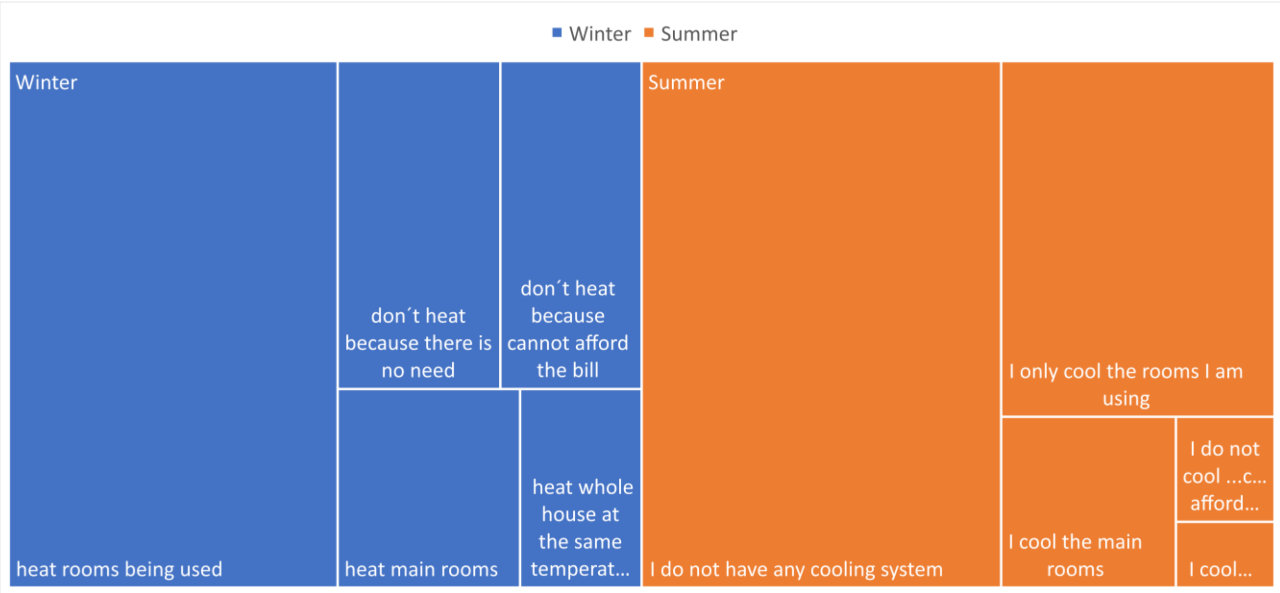


Figure 121. Heating and cooling habits

4.6 Energy efficiency interventions and awareness

The survey in Portugal started with the local context to identify national uses and cultural habits. The first question aimed to identify the available support mechanisms, both local and national, and characterize the user´s awareness of existing support programmes and initiatives (Figure 122). Respondents were given 3 potential measures, social tariff, support to improve energy efficiency and one-stop shops, and they could also provide free text if they were aware of other interesting initiatives. Regarding social energy tariffs, about 10% are covered by a social tariff and 50% are not eligible. The remaining, do not know about it and did not apply. Since social tariff is attributed automatically, it can be assumed that 40% of respondents are not aware of it (and, also, they are not eligible). When we look at the National or Local programmes to support energy efficiency, also around 10% applied and got support (9.6%), and 55% did not apply. Those that are not aware of such programmes are about 23% and 9% were not eligible. Awareness about one stop shop seems to be missing and or not popular as 50% replied do not know and about 42% did not apply. Other support programmes identified by a few respondents are renewable energy communities, incentives for solar PVs and solar thermal and “1º direito in Matosinhos” (a local support given by the municipality for building renovations).

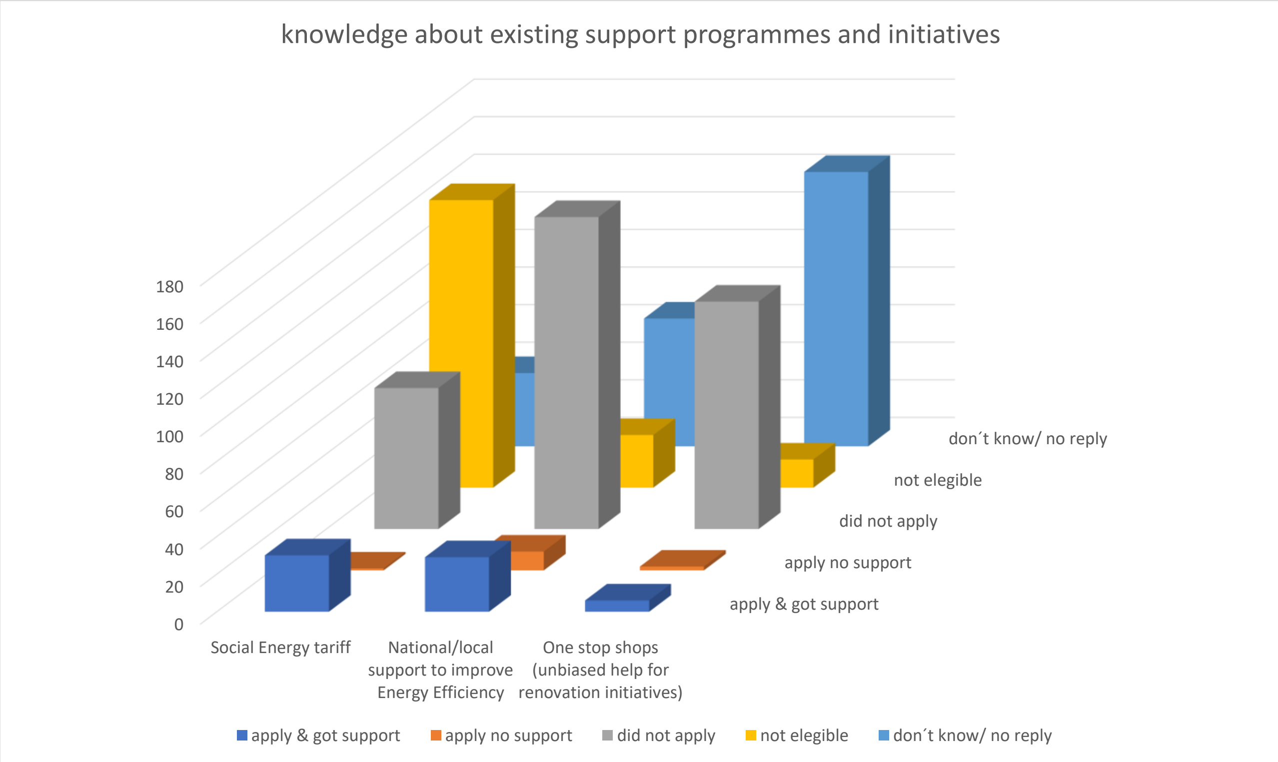


Figure 122. Knowledge about existing support programmes and initiatives

Those that did not apply for support programmes and initiatives had the chance to indicate the three main reasons why, from a list of 10 options, and were asked to rank the three reasons according to the order of importance (Figure 123). The most voted reasons were excessive bureaucracy, uncertainty about what to do in the house and the complexity of the process, followed by the low share of the subsidy provided and uncertainty about the real impact on the energy costs.

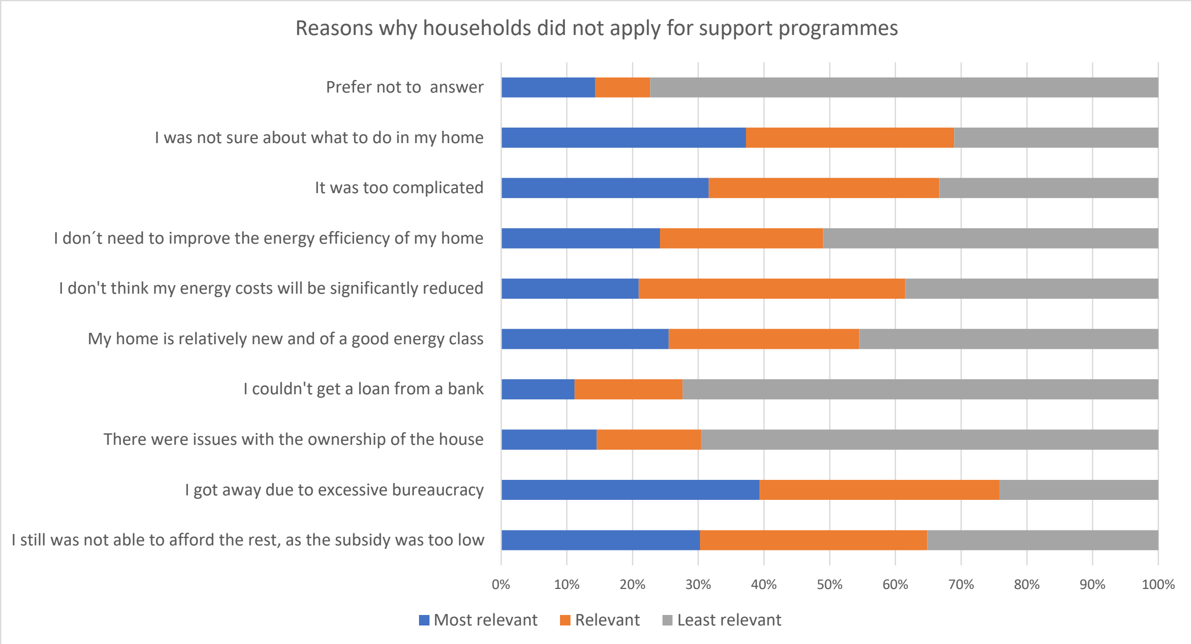


Figure 123. Reasons why households did not apply for support programms

If comparing the results obtained when crossing the support mechanisms and incentives to EE with each tenure type, Figure 124 and Figure 125 can well characterise the situation within our sample:

- Social tariff (Figure 124) is more often given to households living in social housing, which is logical because the criteria to access social housing is associated with income, vulnerability, etc.

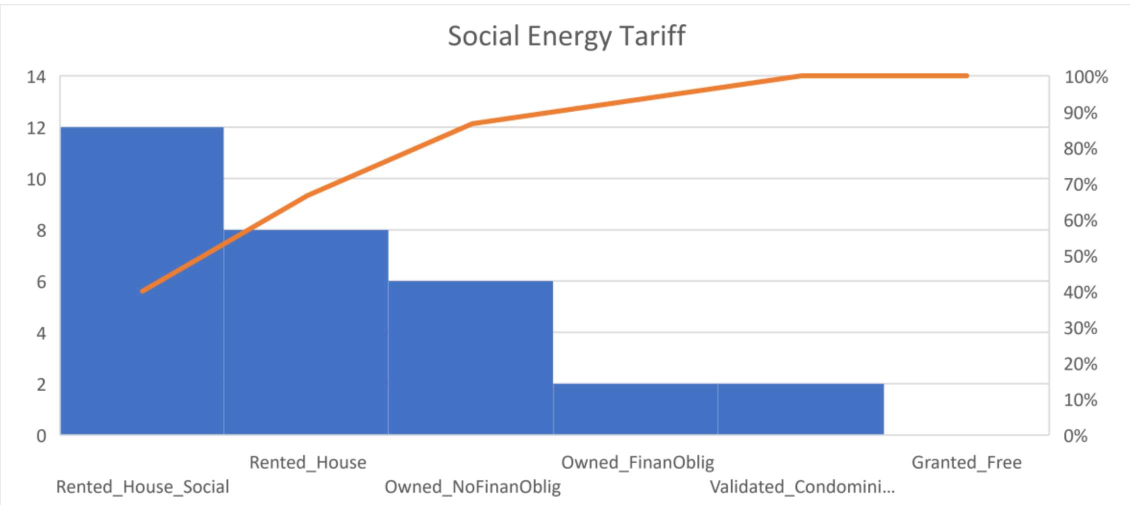


Figure 124. Social energy tariff

- Those applying to support schemes to improve energy efficiency (Figure 125) more often are the households that own the property and do not have bank loans rather than those most in need. This can be an indication of the shortage of budgets, and also of the education level.

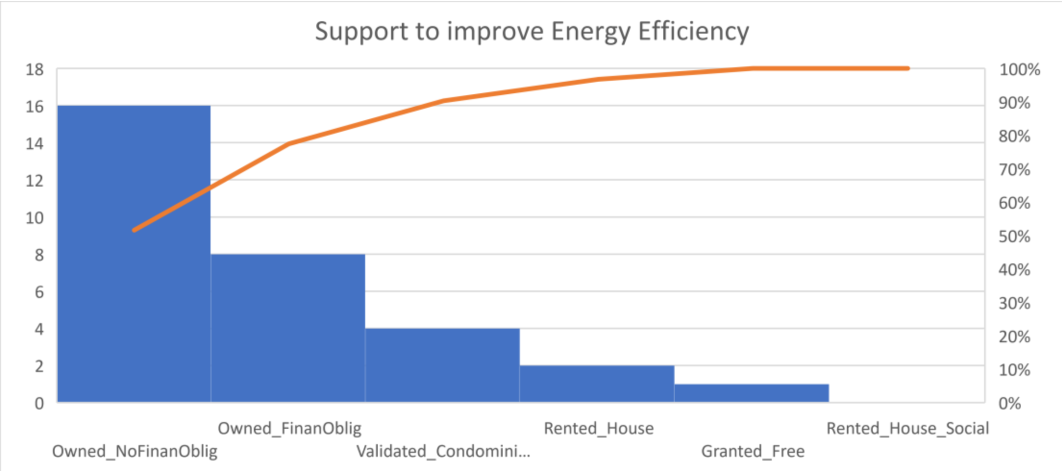


Figure 125. Support to improve energy efficiency

When comparing programmes and supports by tenure and level of education (Figure 126), there is no surprise that those with a technological degree are keener on energy issues and therefore are applying more for EE support measures, and those with low levels of education if have low incomes, automatically receive subsidies from the state, like the social energy tariff, and are not so engaged with applying for support because of illiteracy but also because these are usually complicated processes.

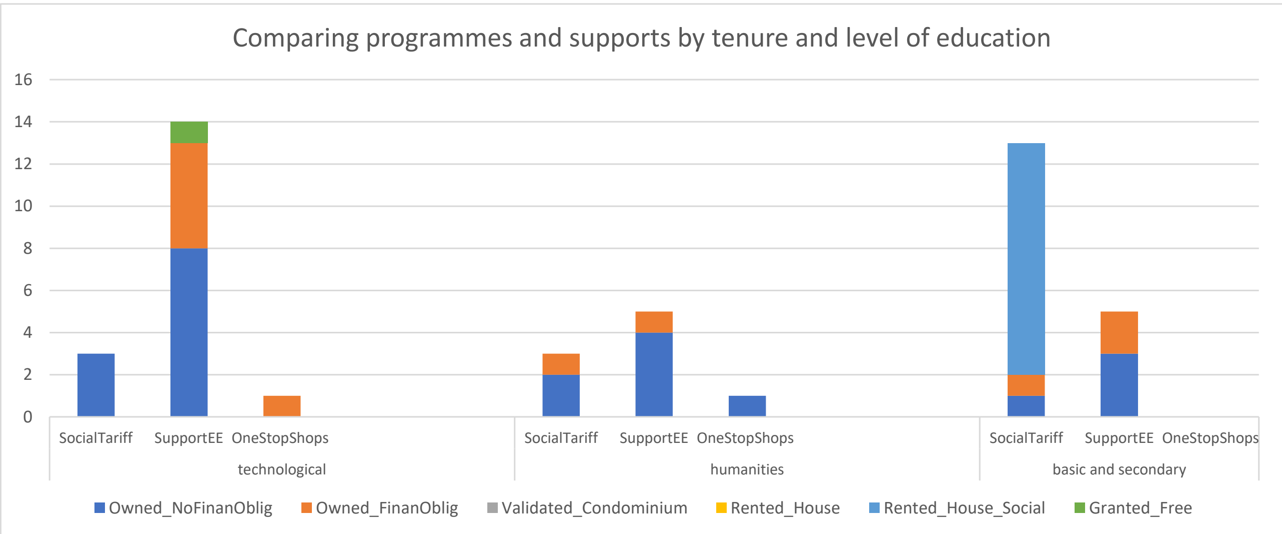


Figure 126. Comparing programmes and supports by tenure and level of education

In a potential scenario of carrying out improvements in their homes, households were asked how much money they could give on a monthly basis to repay the costs of the work. Figure 127 shows that very few households are willing to pay a reasonable amount per month for renovations. There were 26 no replies (8.7%), and 66 households (22%) who would not pay anything as they indicated zero euros, which was not even included in the options provided. 18 households indicate other amounts and provide interesting replies: depends on the upfront costs; the house is rented so no keenness on spending money on retrofits; a retired indicated the amount received per month does not allow other expenses than basics; others indicated the amount 500, 1000, 5000 € at once, but depending on the payback (5 years payback time was indicated by one respondent.

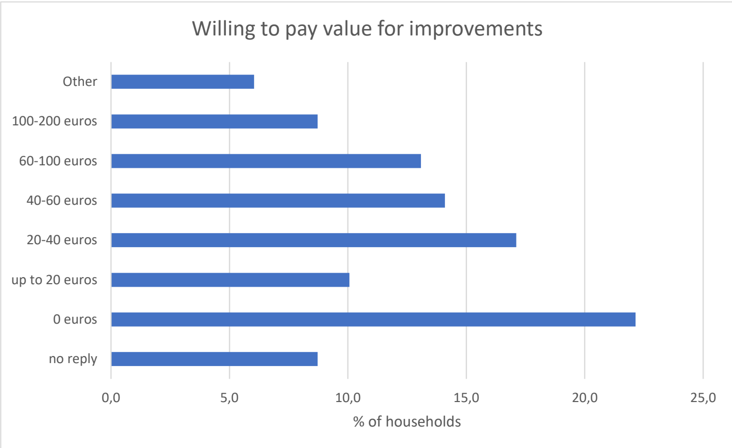


Figure 127. Willing to pay value for improvements

4.7 Energy poverty, vulnerability and behavioural perspectives

Taking into account that the survey was running in the summertime and therefore there should be some bias in the replies, when they were asked about the comfort they feel, self-declared indicators need to be taken with caution.

As can be seen in Figure 128, the correlation between the energy bill and income is not relevant in our sample (there is no direct correlation between both factors). Of course, the sample may not guarantee robust conclusions, but this exercise provides a rough estimate of the share of the monthly energy bill in winter in relation to the available income per month and gives an indication of the effort that low- income people need to pay the energy bills.

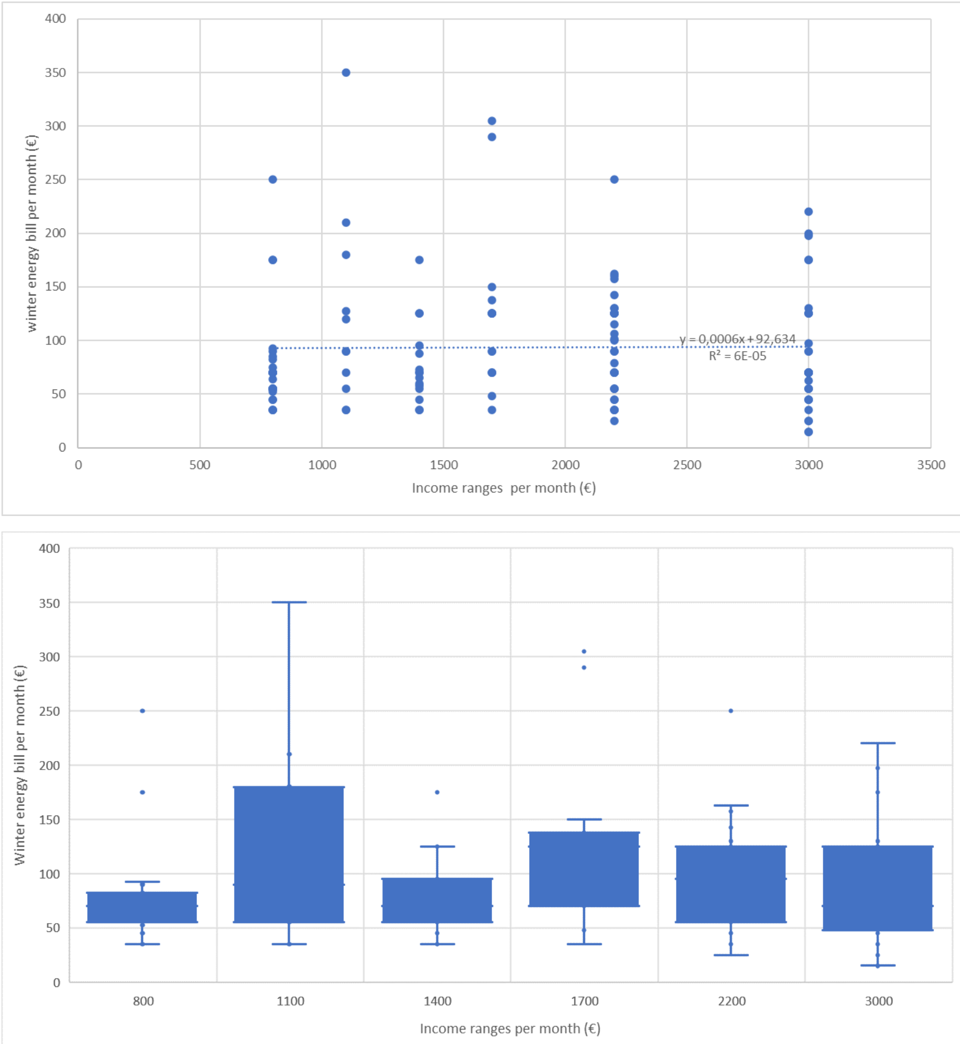


Figure 128. Winter energy bill

Indicator 10% rule

The following charts plot the distribution of energy bills (as a percentage of income) in descending order of frequency, for the lowest income group of households in the sample (Figure 129), and for all respondents (Figure 130), as well as respective cumulative lines (as percentage of the total).

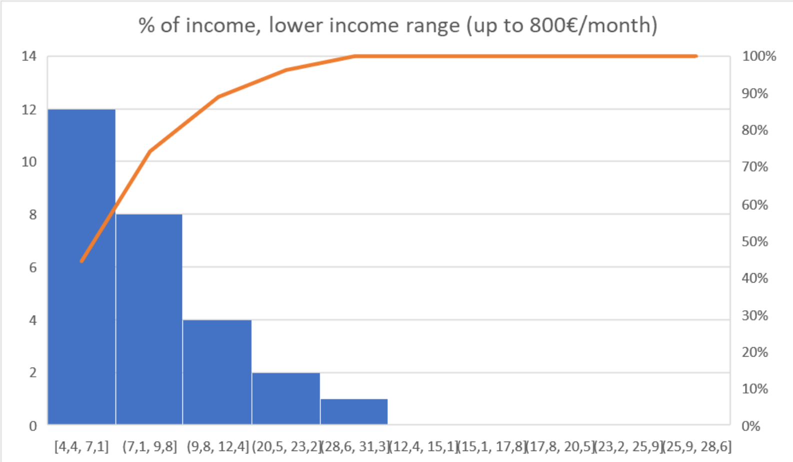


Figure 129. Percentage of income to the lower income range

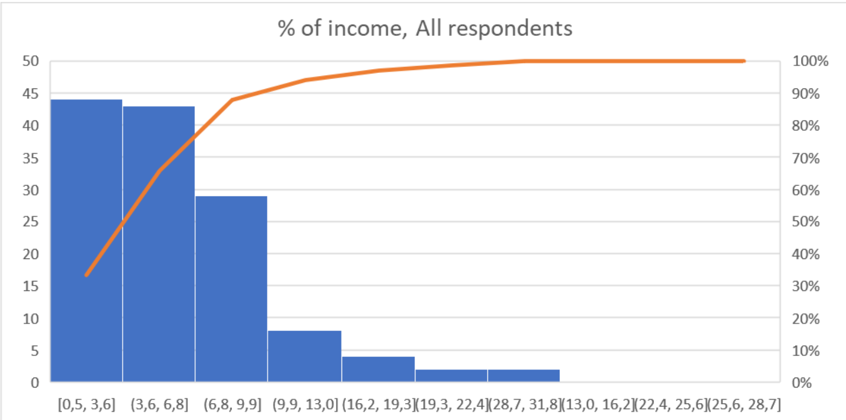


Figure 130. Percentage of income to all respondents

If we look at the overall sample, 88% of respondents' winter energy bills represent less than 10% of their income, and 12% of surveyed households spend more than 10% of their net income on energy services.

If we look only at the lower income households (net income <800€ per month), 29% of surveyed households spend more than 10% of their net income on energy services. Among these, more than 95% indicate they have struggled to pay the bills. 70% of respondents' winter energy bills represent less than 10% of their income; and for 30% represent more than 10%.

Although energy expenses represent a considerable share of household income, when we look at the households with debts to public utilities, our survey indicates that 8.4% of households have failed to pay the energy bills in the last 12 months. The official statistics indicate that 4.5% of the population in Portugal has debts to public utilities, where energy is included, compared with the EU average of 6.2%. It seems the trend is increasing in the last year in Portugal.

Arrears in energy bill

In total 276 households replied to this question (Figure 131). 235 households (85%) declared they had never been in arrears; 9 declared they had already been in arrears for electricity, and 5 for gas. 20 households indicate they rarely are in arrears and if this happens it is because they forget the deadline.

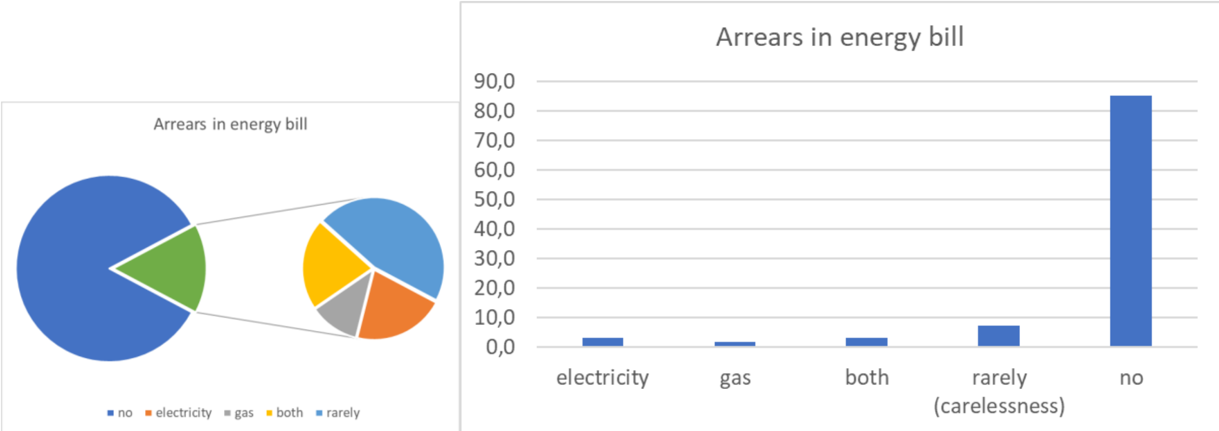


Figure 131. Arrears in energy bill

Declaring they are not in arrears means little about the real energy poverty situation. This indicator is irrelevant because having no debts to public utilities does not give any indication of the effort people make to pay the bills. It also does not give any indication about the comfort levels they are living in. Most people make an effort to pay the electricity bill, because they fear being disconnected, but live with high restrictions on the consumption of goods with a strong impact on comfort and health (see Figure 132). It is important to remember that our sample representativeness has some bias, as the vast majority of replies are from the Coimbra region, where the standard of living is higher than in the majority areas of Portugal.

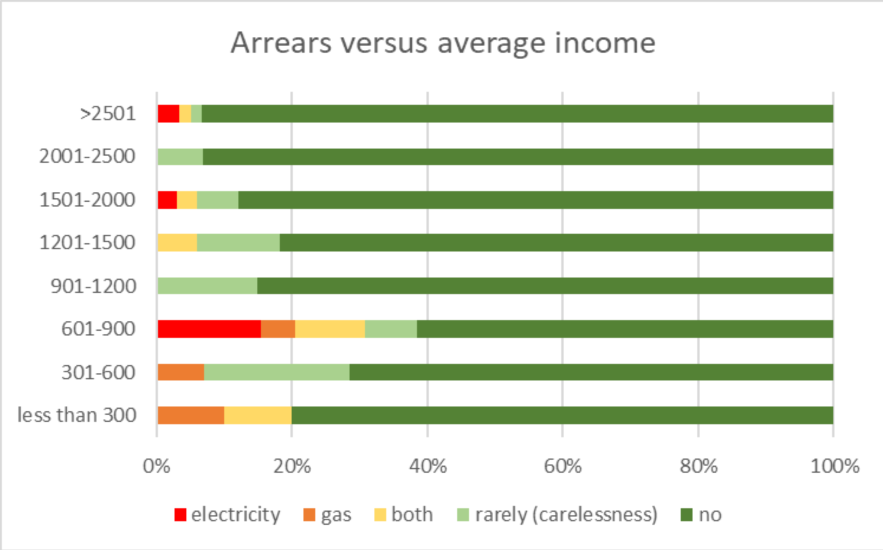


Figure 132. Arrears versus average income

When we analyse arrears and the number of children within the households (any age), it seems there is no positive correlation (Figure 133), on the contrary, what seems to be logical, is as a family always protects its children from vulnerabilities. It is however possible to infer that single parents face higher constraints with paying energy bills. If we look closer at the group single and one child and the monthly income, it is possible to understand that those parents living with the minimum salary (between 601-900 € per month) are the ones more often in arrears.

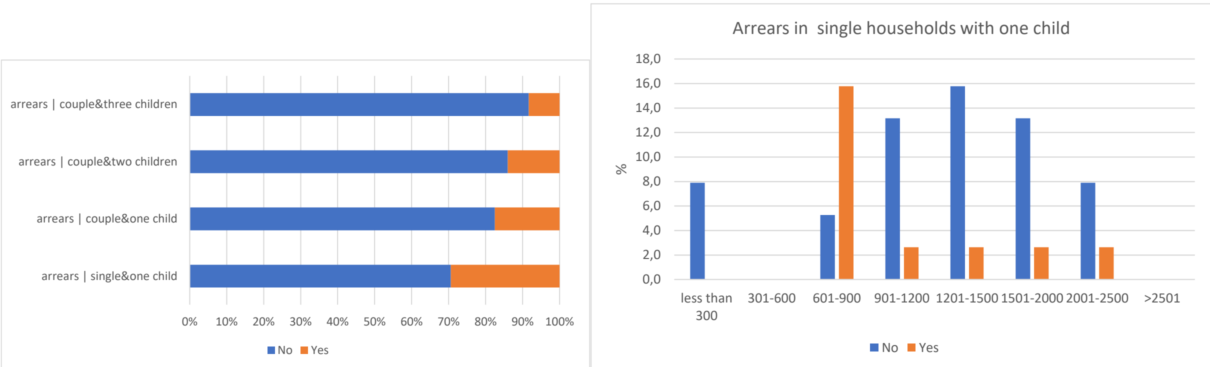


Figure 133. Arrears in single households with one child

Figure 134 shows that the share of households that indicate overall arrears in energy bills and living in a house that is extremely hot in summer and cold in winter, disaggregated by income range, is aligned with previous analysis pointing to the same group of people facing more constraints: those whom income is in the range 601-900 € per month.

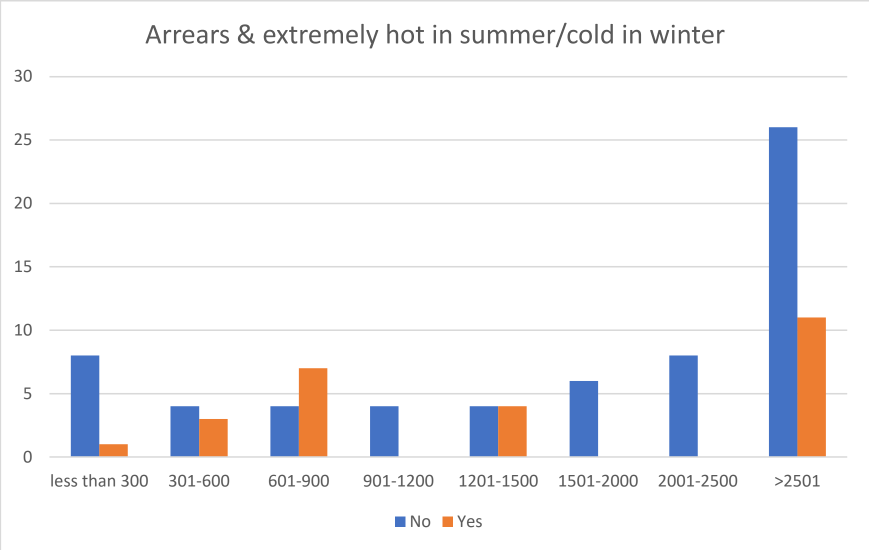


Figure 134. Arrears in extremely hot in summer and cold in winter

When households were asked if they felt they had been forced to restrict other essential needs, they were offered a list of options to select as many as matched their actual situation. Overall, as Figure 135 shows, and surprisingly, only 10% of households, admitted the need to reduce expenses! Among those, the most voted options were reducing transports (37.6%), reducing medical treatments (medicines and consultations) (31.3%), reducing the number of heating hours (28.8%), and thermostat regulation to reduce heating (32.3%).

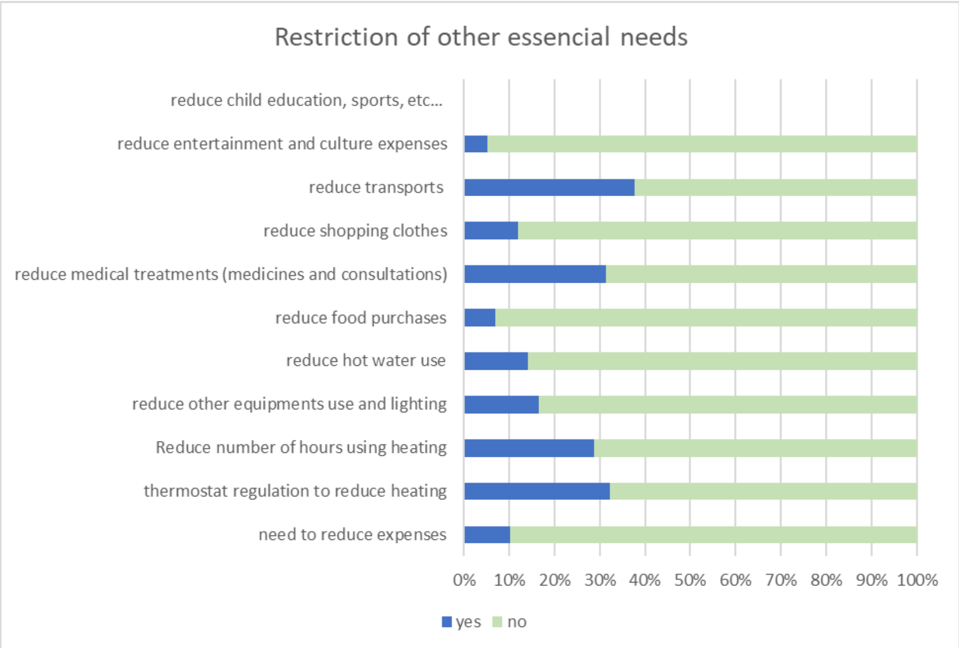


Figure 135. Restriction of other essential needs

Main take outs of the social survey for local action

In general, the survey results do not show a direct relation between household income and energy bills. However, there is an influence of the climate region in the overall energy expenses. In the next figures and considering Guarda is the coldest city in the sample, located in the inner part of Portugal, a "rural" city that is quite small and low industrialised. The average salaries are among the lowest, and the energy expenditure per person and the percentage of energy expenditure in the income are significantly higher. Those people already suffer from living in the peripheral region and in harder climate conditions. It is therefore social just if incentives include some bonification for those living in remote areas.

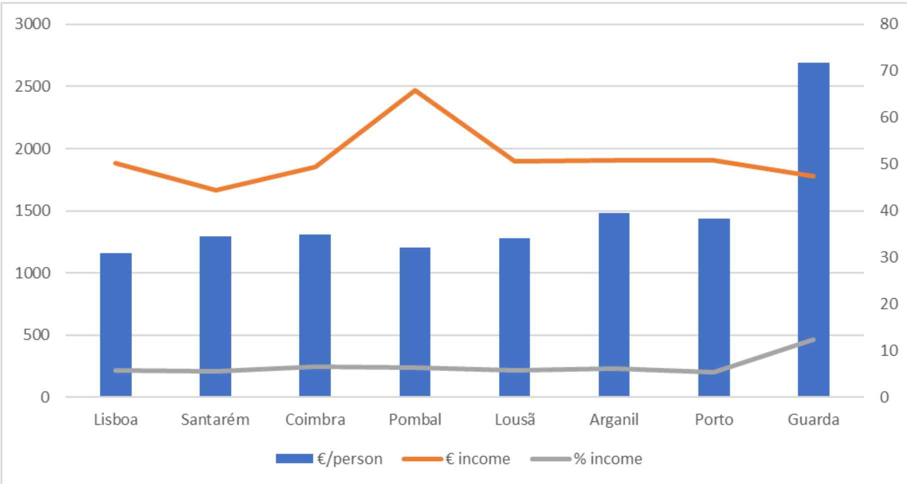


Figure 136. Monthly energy bill per person and income in winter in the different regions covered by the survey

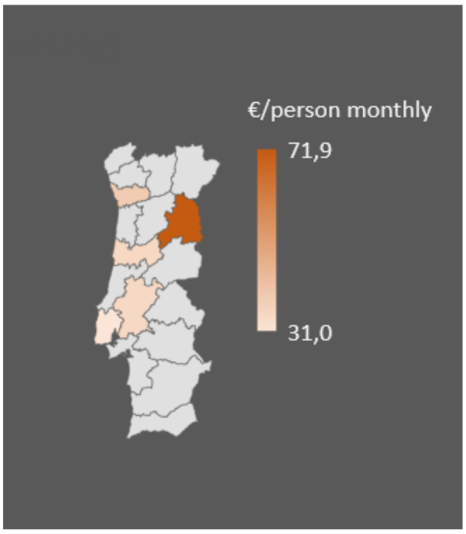


Figure 137. Energy bill per person in Winter (€ / person per month) in five different regions of Portugal (Guarda, Porto, Coimbra, Santarém and Lisboa)

Analysing next figures, it is possible to conclude that energy poverty is clearly related to economic poverty and geographical location. Even if care should be taken as our sample is not robust in terms of representativeness, it is clear that in winter, no matter whether the benchmark used is, € per person or € per square meter, those living in the more inner parts of Portugal face higher effort to pay the energy bills as shown by the trend lines. Establishing regional indicators when policies are being designed for the country, seems to be logical from a social perspective of equity and justice, based on the results of our survey. The debate on regionalisation in Portugal comes up time and time again, especially when there are elections, precisely because regions far from Lisbon and Porto feel disadvantaged in terms of taxation and good governance.

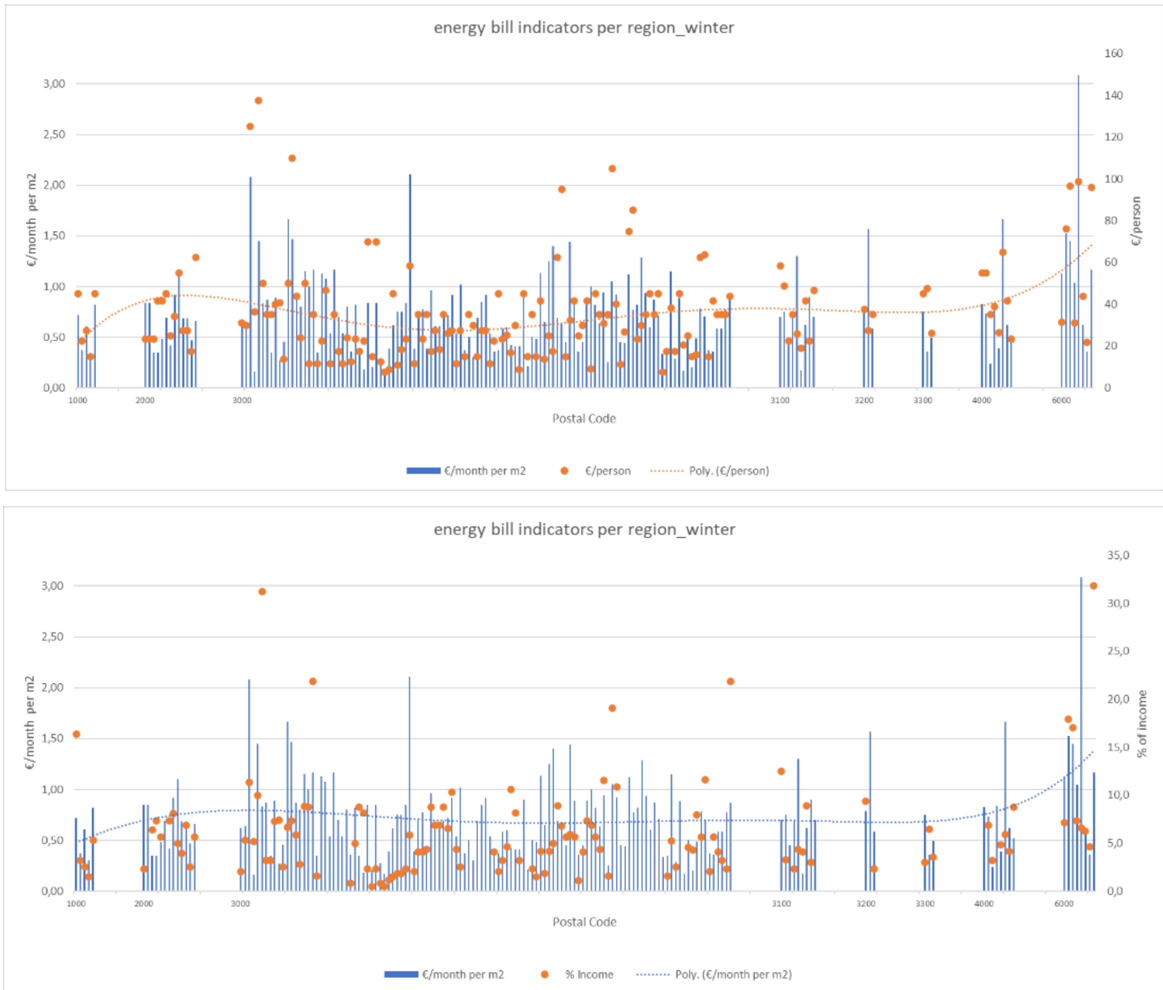


Figure 138. Energy bill indicator per region during winter

In the following picture the self-declared comfort is plotted (a) to see how it compares between the different socio-economic households, as well as (b) the average income, expenses and energy bill, per month within the same region, Coimbra. It is not possible to establish any co-relation between the level of income and the self-declared comfort. Those in the highest income range also represent the highest percentage saying the house is extremely hot and/or cold for this climate. Paradoxically, the lower income households, up to 900 € per month, are among those who self-declared *most comfortable except one week per season and adequately prepared for the* *climate.* A possible justification for this phenomenon, based on the interviews carried out in social houses, is the embarrassment and the fear of losing their home (in case of complains). These are mostly elderly living with very low pensions who are used to live with low temperatures inside.

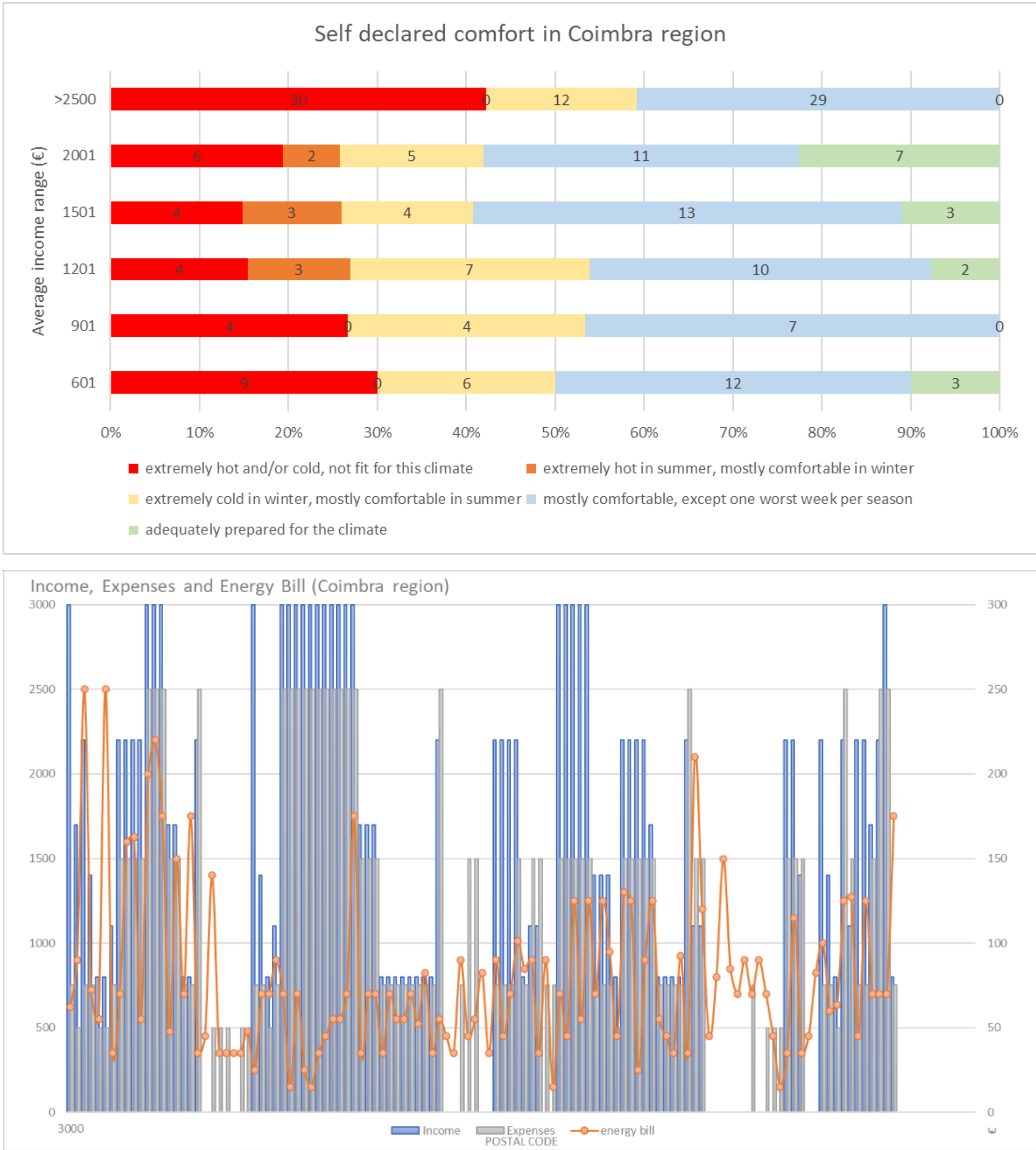


Figure 139. Income, expenses and energy bill

Portugal has been pointed out as being among the most vulnerable countries to energy poverty in the European Union according to several indicators generally used to assess energy poverty (Gouveia et al., 2019). However, there is no official data about the share of Portuguese living in energy poverty. Depending on the indicators used, it is estimated that Portuguese households living in energy poverty range from 15 to 24% of the total (Thomson et al., 2017; Thomson & Snell, 2013). Also, regarding excess winter mortality, which has been considered an indicator of energy poverty due to the negative impacts on the health of living in inadequately heated environments, Portugal has presented one of the highest rates in Europe. Although it has a mild climate, it is surprising that in Portugal there is still a large increase in the number of people dying in cold weather because they cannot afford to heat their homes (Liddell et al., 2015) or do not understand the danger of proper use of heating devices. According to a national newspaper, between 1 November 2018 and 25 January 2019, 19 Portuguese died from cold weather-related accidents: they lost their lives in fires caused by bad electrical connections or heating appliances, or from problems with poorly insulated fireplaces or due to carbon monoxide inhalation. Regarding cooling, around 36% of people living in dwellings are not able to keep the house comfortably cool during the summer (according to Eurostat 2018).

If we add to the relatively mild climate (mild winters) the low household income and high electricity costs (according to Eurostat, in 2017 Portugal was one of the countries with the highest electricity prices for households), it soon becomes clear that the rationale when it comes to managing the household budget will leave air conditioning (heating and cooling) as the last priority, and people use low-efficiency equipment (individual heaters and open fireplaces). Portugal is among the European countries where the poor quality of housing construction and inability to maintain the thermal comfort of the house all year round prevails. A recent National study (Horta et al., 2019) found that households may consider it normal and acceptable to feel both cold and hot at home, either in winter or in summer. This can hinder the social recognition of the EP problem and the need to tackle its negative consequences on the well-being and health of the population. However, until recently, this problem has been mostly neglected by national decision and policymakers.

Nevertheless, driven by European legislation, Portugal has defined the condition of an economically vulnerable consumer as being the beneficiary of extraordinary social support whose percentage discount is applicable on the invoice for electricity and natural gas. However, although these billing support measures (such as social tariffs and energy price reductions) mitigate the financial burden of the most vulnerable families, they have little effect on improving energy comfort. The multidimensional nature of the concept of EP makes it possible to understand that there are other factors that require urgent action since the number of energy-poor Portuguese families is very high and EP seriously affects living conditions, health and comfort. On the other hand, the measures of investment in the efficiency of the dwellings and the acquisition of more efficient electrical equipment improve the conditions of comfort and contribute, indirectly, to the reduction of the energy invoice, allowing to reduction in the number of cases of people who, for economic reasons, could not pay the energy bills. However, support programs and incentives have to be designed to ensure the most vulnerable are reached. According to our survey, in general, existing energy efficiency programmes are not favouring those that need more (lowest income ranges), among other reasons, because those households also have lower education levels. The analysis clarify that Energy Poverty in Portugal is associated with many *Poverties*. Therefore, the multidimensional aspects of *Poverties* need to be addressed, where capacity building and education play an important role.

Beyond defining and measuring energy poverty there is a need to work on developing and improving existing poverty indexes and indicators considering the several dimensions of poverty, targeted to the regions (most inner regions suffer far more), and then design tailor-made effective policies, close to real needs. The pandemic, the rising inflation rate, and the high migration rates intensified inequalities and increased the number of families living with economic constraints. Furthermore, in a scenario of a huge housing crisis in the larger cities in Portugal, Energy Poverty is going far beyond the usual definition, bringing the complexity of *Poverties* to the arena: energy poverty, digital poverty, education poverty, food poverty, etc. Even though environmental impacts from energy production are not the main issue in Portugal, in parallel with energy renovations of the buildings, the promotion of distributed energy generation by supporting renewable energy communities, involving all sectors and society, based on innovative/social focused business models that favour the most vulnerable, can significantly contribute to leverage the welfare of most vulnerable communities. This orchestration of different interests at different levels is the only way possible towards the energy transition leaving no one behind. Far from being a trivial transition, it is important to minimise the inevitable impact on the lives of the most vulnerable Portuguese by promoting the implementation of effective measures and solutions addressing the heating, cooling and indoor air quality of their homes.

References

Andrade, C. (2020). The Limitations of Online Surveys. *Indian Journal of Psychological Medicine*, *42*(6), 575–576. https://doi.org/10.1177/0253717620957496

Daikeler, J., Bošnjak, M., & Lozar Manfreda, K. (2020). Web Versus Other Survey Modes: An Updated and Extended Meta-Analysis Comparing Response Rates. *Journal of Survey Statistics and Methodology*, *8*(3), 513–539. https://doi.org/10.1093/jssam/smz008

Duda, M. D., & Nobile, J. L. (2010). The Fallacy of Online Surveys: No Data Are Better Than Bad Data. *Human Dimensions of Wildlife*, *15*(1), 55–64. https://doi.org/10.1080/10871200903244250

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

Horta, A., Gouveia, J. P., Schmidt, L., Sousa, J. C., Palma, P., & Simões, S. (2019). Energy poverty in Portugal: Combining vulnerability mapping with household interviews. *Energy and Buildings*, *203*, 109423. https://doi.org/10.1016/j.enbuild.2019.109423

Kostakis, I., & Lolos, S. (2022). Residential demand for electricity: Empirical evidence from Greece using pseudo-panels. *Energy, Ecology & Environment*, *7*(1), 51–69. https://doi.org/10.1007/s40974-021-00225-2

Liddell, C., Morris, C., Thomson, H., & Guiney, C. (2015). Excess winter deaths in 30 European countries 1980–2013: A critical review of methods. *Journal of Public Health*, fdv184. https://doi.org/10.1093/pubmed/fdv184

Thomson, H., Bouzarovski, S., & Snell, C. (2017). Rethinking the measurement of energy poverty in Europe: A critical analysis of indicators and data. *Indoor and Built Environment*, *26*(7), 879–901. https://doi.org/10.1177/1420326X17699260

Thomson, H., & Snell, C. (2013). Quantifying the prevalence of fuel poverty across the European Union. *Energy Policy*, *52*, 563–572. https://doi.org/10.1016/j.enpol.2012.10.009

Annex III: Social survey questionnaire

SECTION 1: YOUR RESIDENCE

1. Your type of residence is:

Detached house (one level)	
Detached house (two levels)	
Apartment - on the ground floor of the building………………………………….	
Apartment - on the first floor above a loft……….	
Apartment - on the top floor of the building…………………..	
Apartment – on an intermediate floor of the building………………………	
Other (Specify)……………………………………………………………… …	

2. When was your residence built?

- Before in 1946		- 1996 - 2005	
- 1946 - 1960		- 2006 - 2011	
- 1961 - 1980		- 2012 - 2016	
- 1981 - 1995		- 2017 onwards	
I do not know		I prefer not to answer	

3. How much is your home (in square meters)?

Less than 50 m^2		From 90 m^2 up to 100 m^2	
From 50 m^2 up to 60 m^2		From 100 m^2 up to 120 m^2	
From 60 m^2 up to 70 m^2		From 120 m^2 up to 140 m^2	
From 70 m^2 up to 80 m^2		From 140 m^2 up to 160 m^2	
From 80 m^2 up to 90 m^2		Over up to 160 m^2	
I do not know		I prefer not to answer	

4. In addition to the bathroom and storage areas, how many rooms are there?

1	☐
2	☐
3	☐
4	☐
5	☐
More than 5	☐
I prefer not to answer	☐

5. Your residence:

It is privately owned with no financial obligations (loan, mortgage, etc.)	☐
It is privately owned with financial obligations (loan, mortgage, etc.)	☐
It is for rent residence belonging to a private person	☐
It is for rent residence belonging to the Municipality	☐
Given to us for free (by family, employer, or others)	☐
Other (Specify) ……………………………………………………………………….	☐
I prefer not to answer	☐

SECTION 2: ENERGY ISSUES

6. How is your home heated? (Select one main type. Also, you have the option to choose any secondary systems)

	Primary	Secondary
Oil central heating		
Central heating with natural gas		
Gas central heating (LPG)		
Central heating with firewood / pellets		
Individual heating with natural gas		
Stove of firewood / pellets		
Individual oil stove (Number: ………)		
Individual gas stove (Number : ……………)		
Personal electrical appliances (Number : ……………)		
Air conditioners (Number : ……………)		
Thermal accumulators (Number : ……………)		
Heat pumps		
Open fireplace		
Energy fireplace		

Other (Please specify)…………………………………………………………………………

My house is not heated ☐

7. How do you heat the hot water you use in various daily uses (e.g. bathing, washing, etc.)

With electric water heater	
With rapid heater	
With solar water heater	
With boiler	
I do not know	
I have no hot water in my residence	

8. Have any of the following energy saving measures been implemented or are they going to be implemented in the home you live in?

	Yes, in the last decade	Yes, in the next five years	Yes, in the next five years but only if there is some subsidy	I don't think about it/I don't need to	I do not know I do not answer
(1) Energy efficient windows					
(2) Wall/ceiling insulation					
(3) New heating system or cooling					
(4) Installation of a solar water heater					
(5) New energy efficient electrical appliances					
(6) Photovoltaics on the roof					
(7) Energy saving lamps					
(8) Other (Please specify)					

9. Please tick some of the following phrases that apply to your household/residence

	Yes	No
(1) Damp/mold appears on walls/ceilings/floors		
(2) The house is warm and cozy during the winter		
(3) The house is cool and comfortable during summer		
(4) There is a delay in paying energy bills (electricity/heating) in the last 12 months (<u>H: for electricity, T: for heating, T: for both</u>)		
(5) There has been an interruption of the electricity connection or natural gas supply due to late payment of bills in the last 12 months		
(6) There has been an interruption of the central heating in your apartment building by decision of a general assembly or due to non-payment of utilities		

I prefer not to answer ☐

10. Have you had to cut back on your basic needs to pay your electricity/heating bills in the last 12 months?

	Yes	No
(1) Cut spending on food		
(2) Cut spending on drugs		
(3) Restriction on use of electrical appliances/lighting		
(4) Limiting the use of hot water		
(5) Cut spending on clothes, shoes, etc.		
(6) Limitation on home heating		
(7) Cut back on commutes		
(8) Cut entertainment expenses		
(9) Cut education costs (schools, conservatories, etc.)		

(10) Other (specify)……………………………………………………………………………………………………

I prefer not to answer ☐

11. What kind of restrictions do you place on the heating of the house (<u>If you answered "yes" to question 10, to the phrase "restriction on the heating of the house"</u>)

	Yes	No
(1) Shut off the heating even when the house is cold		
(2) Reduction of operating hours of the heating system		
(3) Heating only one part of the house		

(4) Other (specify) ……………………………………………………………………………………………………

I prefer not to answer ☐

12. Have there been health problems (for you or other members of your household) due to insufficient heating and/or humidity, such as arthritic/rheumatic diseases, frequent colds, etc.?

Yes ☐ No ☐ I prefer not to answer ☐

13. During the winter, on average, how many hours do you turn on the heating system?

Less than 2 hours ☐
2 – 4 hours ☐
4 – 6 hours ☐
6 – 10 hours ☐
More than 10 hours ☐
We don't turn on the heating at all ☐

The system is open 24 hours a day with the thermostat at a specific temperature ☐
I do not know ☐
I prefer not to answer ☐

14. What is the average temperature in your home in winter?

≤ 15 °C	☐	18-21 °C	☐	Do not know	☐
15-18 °C	☐	> 21 °C	☐	I prefer not to answer	☐

15. In your opinion, what is the ideal indoor temperature in winter?

≤ 15 °C	☐	18-21 °C	☐	Do not know	☐
15-18 °C	☐	> 21 °C	☐	I prefer not to answer	☐

16. Have you received any kind of social benefit that helps you meet your energy needs?

Yes ☐ No ☐ I prefer not to answer ☐

If yes, please specify the type of social benefit

Heating benefit	☐
Social Household Tariff	☐
Unemployment benefit	☐
Minimum Guaranteed Income (Social Solidarity Income)	☐
Housing allowance	☐

17. Are you a beneficiary of Social Household Tariff (SHT)?

Yes ☐ No ☐ I prefer not to answer ☐

18. Please indicate whether you agree or disagree with the following statements

Statement	**Disagree**	**I guess I disagree**	**I guess I agree**	**Agree**
(1) The state should support households that cannot pay for their energy needs with subsidies				
(2) The state should support households that cannot pay for their energy needs with home energy renovation programs				
(3) Energy suppliers treat low-income consumers fairly (e.g. through more installments)				
(4) The Municipality should inform citizens about energy renovation programs for homes				

I prefer not to answer ☐

19. Have you ever joined an energy saving subsidy scheme?

Yes ☐ No ☐ I prefer not to answer ☐

If not, for what reasons? Please specify up to three reasons, in order of importance (1: the most important of the three and 3: the least important of the three)

I couldn't afford it, the subsidy is low	
I was not aware that such subsidy programs existed	
I was scared of bureaucracy	
There were issues with the ownership status of the house	
I couldn't get a loan from a bank	
My residence is relatively new and has a good energy class	
I don't think my energy costs will drop significantly	
I am a tenant and was not eligible to apply	
Other:……….	

If you have not yet joined an energy saving subsidy scheme, would you be interested in joining in the future?

Yes ☐ No ☐ I prefer not to answer ☐

If not, why?

For the reasons stated above	
Different reason:……………………………………………………………………………………………………	

20. Assuming you wanted to upgrade your home energy-efficiently, how much money could you afford, on a monthly basis, to pay off the cost of the work?

Up to € 20		€80-100		€ 250-300	
€ 20-40		€ 100-150		€ 300-350	
€ 40-60		€150-200		€ 350 - 400	
€ 60-80		€ 200-250		Over € 400	

I would not be able to give anything due to low income	
I wouldn't give anything because I'm not interested in investing in energy saving	

21. Over the past 12 months to date, the average monthly home electric bill is:

I know an average monthly cost, based on the total annual spend ☐

A. In winter:

< €10	☐	€40-50	☐	€100-150	☐
€10-20	☐	€50-60	☐	€150-200	☐
€20-30	☐	€60-80	☐	€200-300	☐
€30-40	☐	€80-100	☐	> €300	☐

Or specify €...............................

B. In the summer:

< €10	☐	€40-50	☐	€100-150	☐
€10-20	☐	€50-60	☐	€150-200	☐
€20-30	☐	€60-80	☐	€200-300	☐
€30-40	☐	€80-100	☐	> €300	☐

Or specify €...............................

I prefer not to answer ☐

22. In the last 12 months to date, the monthly household gas bill is:

A. In winter:

Less than €10	☐	€40-50	☐	€100-150	☐
€10-20	☐	€50-60	☐	€150-200	☐
€20-30	☐	€60-80	☐	€200-300	☐
€30-40	☐	€80-100	☐	> €300	☐

Or specify €...............................

B. In the summer:

Less than €10	☐	€40-50	☐	€100-150	☐
€10-20	☐	€50-60	☐	€150-200	☐
€20-30	☐	€60-80	☐	€200-300	☐
€30-40	☐	€80-100	☐	> €300	☐

Or specify €...............................

I prefer not to answer ☐

23. If you use oil, LPG, firewood / pellets, how much money do you spend, on average, for heating (choose whether you want to declare per month or in total for the winter season)?

A. Per month:

Less than € 20	☐	€80-100	☐	€ 250-300	☐
€ 20-40	☐	€ 100-150	☐	€ 300-350	☐
€ 40-60	☐	€150-200	☐	€ 350 - 400	☐
€ 60-80	☐	€ 200-250	☐	Over € 400	☐

B. Overall during the winter (beginning of November until April 15)

Less than € 200	☐	€ 500-600	☐	€ 1250 - 1500	☐
€ 200-300	☐	€ 600-800	☐	€ 1500 - 1750	☐
€ 300-400	☐	€ 800-1000	☐	€ 1750 - 2000	☐
€ 400-500	☐	€ 1000-1250	☐	Over € 2000	☐

24. Please note if the following phrases apply to your household/home

	Yes	No
(1) I often check the electricity meter reading		
(2) I compare the power consumption with previous years		
(3) I read the amount of consumption (kWh) on the electricity bill		
(4) I understand the charges on my electricity bill		
(5) I read information/informative material that comes with the electricity bill from the electricity supplier		
(6) I read information/informative material on energy saving from other bodies (e.g. consumer associations, regulatory authorities, etc.)		
(7) I follow the energy saving instructions given by the electricity supplier or other bodies (e.g. consumer associations, regulatory authorities, etc.)		
(8) I have installed a smart digital meter and am regularly updated on my consumption		
(9) I use night current		

I prefer not to answer ☐

SECTION 3: DEMOGRAPHICS

D1. Sex

Woman	☐	Other	☐
Man	☐	I prefer not to answer	☐

D2. Zip code of residence

____

I prefer not to answer ☐

D3.	What is your age;	______	I prefer not to answer	☐
D4.	How many people does your household consist of?	______	I prefer not to answer	☐
D5.	How many of them are children under the age of 5?	______	I prefer not to answer	☐
D6.	How many children are pupils/students?	______		☐
D7.	How many people are retired?	______	I prefer not to answer	☐
D8.	How many of them are full-time employees?	______	I prefer not to answer	☐
D9.	How many of them are part-time workers?	______	I prefer not to answer	☐
D10.	How many of them are disabled or have a long-term illness?	______	I prefer not to answer	☐
D11.	How many people are long-term unemployed?	______	I prefer not to answer	☐

D12. What is the highest level of education among members of your household?

Elementary school has not been completed	☐	Secondary professional	☐
Primary school	☐	Post-secondary professional	☐
Middle School/ High School	☐	Higher education	☐
		I prefer not to answer	☐

D13. What was the net monthly income of your entire household (including allowances, rental income etc.)?

Up to €250	☐	€1,001 – €1,250	☐
251 – 520 €	☐	€1,251 – €1,500	☐
€521 – €680	☐	€1,501 – €1,950	☐
€681 – €850	☐	– €1,951 – €3,300	☐
€851 – €1,000	☐	€3,301 and above	☐
I prefer not to answer	☐		

Please specify €................................

D14. How would you describe your income?

It is difficult to survive on my current income	☐
I manage with my income	☐
I live comfortably on my income	☐
I prefer not to answer	☐

D15. What are your total household expenses each month to cover all your needs, i.e. rent or mortgage payment, transport, heating, water, electricity, telephone, council charges, food, clothing, entertainment, education, etc. etc.?

Up to €250	☐	€1,251 – €1,500	☐
251 – 520 €	☐	€1,501 – €1,750	☐
€521 – €680	☐	€1,751 – €2,000	☐
€681 – €850	☐	€2,001 – €2,500	☐
€851 – €1,000	☐	€2,501 and above	☐
€1,001 – €1,250	☐		☐
I prefer not to answer	☐		

D16. Would you like one of our project partners to visit you to offer you more information on energy saving issues?

Yes ☐ No ☐

If so, please email to …………….. with your request and message title "REVERTER" and a representative of ………………… will contact you immediately.