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Framing the context of energy poverty in Croatia: A case-study from Zagreb

Goran Grdenić [a,*], Marko Delimar [a], Slavica Robić [b]

[a] University of Zagreb Faculty of Electrical Engineering and Computing, Unska 3, 10000, Zagreb, Croatia
[b] Society for Sustainable Development Design, Janka Rakuše 1, 10000, Zagreb, Croatia

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ABSTRACT

Like many other European countries, Croatia is also missing a systematic and adequate policy framework to tackle the problem of energy poverty. Currently, there is no distinction between energy and general poverty in Croatian legislation, and direct payments of utility bills are the only measure of help to (energy) poor households. Local and national authorities are lacking validated facts to make informed investments that would make a long-term impact on lowering energy demand, but also improving living conditions and quality of life of energy poor. To collect relevant data, 102 energy poor households in the City of Zagreb were visited and surveyed. Data analysis revealed a significant share of citizens living in low energy-efficient dwellings reducing heating during winter and with draught and mould problems. Wall retrofitting investment was investigated more closely by calculating a simple payback period and proving to be a cost-effective measure with many positive direct and indirect implications. The higher share of rented apartments in the group of the most energy-intensive dwellings presents a potential obstacle in conducting energy-efficiency measures and should anticipate the adoption of stricter renting regulations.

1. Introduction

Energy (fuel) poverty is one of the significant issues in the European Union, and the Republic of Croatia is no exception. On the one hand, although there is no universal agreement on any definition of energy poverty, a basic qualitative definition of energy poverty is intuitively understandable for most – it represents the inability of a household to afford its primary energy needs. Primary energy needs, thereat, include the energy for indoor heating and cooling, cooking, lighting, washing and water consumption. On the other hand, a quantitative definition is even more challenging, without a unique definition, i.e. indicator on the EU level and consensus among researchers. The three most applied objective income-based definitions/indicators are the following:

- in literature, one of the most cited is definition given by Boardman according to which a household is energy poor if it needs to spend more than 10% of its incomes to adequately heat the home (Boardman, 1991);
- the second is minimum income standard (MIS) indicator according to which a household is energy poor if the income available after meeting the basic needs is not sufficient for covering energy expenditures (Moore, 2012);
- the third well known quantitative definition is low-income high-cost (LIHC) method in which a household is considered energy poor if it has above-average modelled energy costs, and if after paying these energy bills falls below a poverty line (Hills, 2012).

Lack of an official legal definition at the EU level obstructs the monitoring of the number of energy poor and thus hampering the relevant political decision making targeted specifically to help energy poor households. In the meantime, the problem of energy poverty is growing in many European countries because of rising fuel prices, low energy efficiency of the housing stock and household appliances and social inequalities (Boardman, 2012; Bouzarovski et al., 2012; Recalde et al., 2019). While energy poverty and fuel poverty are often observed as synonyms for the same problem, where fuel poverty is more used in UK and some western EU countries and energy poverty is official term in the EU legislation, the difference between the use of the terms “energy poverty” and “fuel poverty” needs to be elaborated. The common approach is to refer the term of “energy poverty” to issues of energy access in primarily developing countries, and the term of “fuel poverty” is referred to issues of energy affordability, primarily in developed countries (Li et al., 2014); however, a consensus in the literature is still missing and although Li et al. argue that energy poverty is referring only

* Corresponding author.
E-mail address: goran.grdenic@fer.hr (G. Grdenić).

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to developing countries it is a term officially used on EU level.

Regardless of the different definitions, it needs to be emphasized that energy poverty is unanimously a unique problem, distinct from a general poverty problem. First, energy poor households are not necessarily income-poor, and vice versa. Second, the energy poverty problem is closely related to efficiency of the housing stock and household appliances with implications on the health and well-being of the population, as well as energy consumption and reducing greenhouse gas emissions.

There are three main elements whose interdependency influences the appearance of energy poverty: household income, energy prices, and energy efficiency of a dwelling, also including the efficiency of devices (Boardman, 1991). Depending on which of the three has a dominant role (Burlinson et al., 2018), identify three dimensions of energy poverty: poverty caused by low income, poverty caused by high housing costs, and poverty caused by high energy costs. Efforts to alleviate energy poverty should thus include the following measures: increasing the incomes, lowering energy prices through special tariffs, and increasing the energy efficiency of dwellings and household appliances. The last one is the most effective, with many advantages at the societal level (European Commission, 2011; Dubois and Meier, 2016). Direct payments, influencing the income of dwellers, only have short-term effects and generally do not contribute to removal of energy poverty causes, and it would be likely in most cases be significantly more effective to reroute these funds into energy efficiency improvements (Hills, 2012; Robić, 2016). However, as improving efficiency of dwellings is often costly this is usually a long-term process, thus short-term measures are further necessary.

Besides the above three dimensions, socio-demographic and geographical dimensions are additional elements of the energy poverty problem that cannot be neglected. Researches conducted on Italian and Dutch case studies (Besagni and Borgarello, 2018; Brounen et al., 2012) showed that dwelling characteristics have the dominant influence on thermal energy consumption, while the socio-economic characteristics of dwellers (income, family composition, age, employment, health, etc.) have the dominant influence on electrical energy consumption. The research conducted by (Longhi, 2015) on UK case study does not differentiate between the thermal and electrical energy consumption but in line with the above mentioned research, it also confirms that socio-economic characteristics have a statistically significant impact on per-capita energy expenditures, although much lower in comparison to dwelling characteristics. These findings have important consequences on the policies aiming at improving energy efficiency in the residential sector. Increasing wealth, aging of the population, an increasing proportion of people living alone or in small families, increasing the accommodation size, etc. may potentially offset energy savings achieved by energy efficiency measures.

Findings from (Besagni and Borgarello, 2019) suggest that energy poverty is more related to the geographical dimension in comparison to the socio-demographic dimension in the Italian case. Without taking into account cooling needs, energy poverty is more pronounced in the north of the country, in colder climates. These conclusions also confirm the distinction between energy and general poverty; northern regions of Italy are mostly affected by energy poverty issues, and southern regions are affected by general poverty issues. Calculation of the LIHC indicator on the England study case (Robinson et al., 2018), reveals a higher prevalence of energy poverty in inner-city areas and larger spatial heterogeneity in comparison to the 10% indicator. However, special caution needs to be taken to generalize these findings to other areas or countries.

Energy-efficiency measures, the most effective in energy poverty alleviation in the long-term as mentioned already, can further be decomposed into active, passive, and management/information measures (Capdevila et al., 2012). Active measures are related to the improvement of heating/cooling systems, passive measures are primarily linked to the thermal insulation of passive structures, and management/information measures are oriented towards the behavior of dwellers. In (Hills, 2012) was shown that the measures of increasing thermal efficiency of buildings are the most cost-effective. However, management/information measures should not be neglected, as particularly in the social housing sector, the behavior of household members has a large effect on energy savings (Romero Rodríguez et al., 2018). A retrofitting of a building envelope, in addition to energy savings, also has a few indirect advantages which are often hard to measure and are thus not often considered in the assessment of the cost-effectiveness of a certain project. These include a positive impact on health and enhancement of life quality of household members (Frieden, 2010; Heffner and Campbell, 2011; E4The Future, 2016; Marmot Review Team, Friends of the Earth, 2011; Robić and Ančić, 2018; Ortiz et al., 2019). The measured energy savings, achieved through thermal insulation of a dwelling, are lower than the calculated savings, the so-called "prebound" effect (Galvin and Sunikka-Blank, 2013; Michelsen and Muller-Michelsen, 2010). This effect is especially emphasized in energy poor households because energy poor are forced, usually primarily because of financial reasons, to reduce the energy use bellow what would be the culturally considered adequate amount, i.e. reduce the heating during winter in some rooms, or they only heat one room in an apartment (as will also be seen from the survey conducted in this research). For this reason, the "prebound" effect should not present an obstacle in conducting thermal renovation measures in energy poor households because of its co-benefits on resident's health and quality of life.

Support in paying the utility bills and prevention of disconnections for some vulnerable groups have been so far the only measures to alleviate the burden of the income-poor households in Croatia. Moreover, energy poverty in the Croatian legislation is closely linked with income poverty. However, the situation is starting to improve, primarily thanks to the demands of the European Union. The development of "The program for energy poverty alleviation" has been foreseen as one of measures in "The 4th National Energy Efficiency Action Plan (NEEAP, 2017–2019)" and in the "Integrated energy and climate action plan" (Government of the Republic of Croatia, 2019; Ministry of Environmental Protection and Energy, 2017; Ministry of Environmental Protection and Energy, 2019). However, despite the fact NEEAP presented measures to be implemented by the end of 2019, Program has still not even been drafted. Another sign of progress in Croatian energy poverty policy landscape is that part of the energy efficiency retrofitting fund has in 2020 been directly allocated to poor households, covering 100% of their investment costs in the improvement of energy efficiency of dwellings (Ministry of Construction and Physical Planning, 2020). One of the main challenges in energy poverty struggle is that local and national decision makers are lacking validated facts upon which to make informed investment decisions. Therefore, the objective of this research, conducted as a part of "FER solutions for a better community" project (Society for Sustainable Development Design, 2020), is the proposal of measures for mitigating energy poverty in the City of Zagreb, capital of Croatia. To achieve this, 102 poor households were visited and surveyed. Based on the collected data, the payback period calculation has been derived for retrofitting walls, which was proven to be a cost-effective method to combat energy poverty.

Particular attention should be dedicated to tenants because it is more difficult to conduct thermal retrofitting measures in such accommodations. The percentage of tenants varied greatly in different European countries, from only 3.6% in Romania to 48.5% in Germany in 2019 (European Commission, 2020). In (Rehdanz, 2007) was showed that energy expenditures are lower in owner-occupied dwellings because the owners are more willing to invest in energy efficiency measures. In Croatia, with a tenancy rate of only around 10%, there is no specific law or rules which would regulate the issue of investments in rented apartments. The positive example and possible role model could be UK Green Deal (Hough and White, 2014) in power from 2012 to 2015 in which necessary investment loans were attached to properties, not the owners, and the loans were repaid from achieved energy savings. Shifting the financial burden of thermal renovation directly to tenants through increased renting rate can lead to migration of residents to lower energy-efficient buildings (Groβmann et al., 2014; Wolff et al., 2017).

The rest of the article is organized in the following way. In the second chapter, the actual state of energy poverty in Croatia is presented comparatively to the EU average through selected economic and living conditions statistics. Afterward, the current legal measures aimed at helping (energy) poor households are introduced. The third chapter presents the results and discussion on the socio-demographic and dwelling characteristics and the selected responses from the questionnaire from the field visits to poor households in the City of Zagreb. The model for the payback period of wall retrofitting is developed in the fourth chapter. The input data, results of the model and accompanying discussion are presented. The final remarks and conclusions of the paper are given in the final chapter.

2. Energy poverty in the Republic of Croatia

2.1. Indicators of Croatia in the EU context

In this section, a comparative analysis of selected economic and living conditions parameters from EUROSTAT (European Commission, 2020) is presented for Croatia and the European Union average. The key energy poverty indicators – energy prices and incomes – are analyzed first. In Fig. 1a and b) electricity and natural gas prices for household consumers including all taxes and levies are depicted for the period from 2010 to 2018. The electricity prices in 2018 in comparison to 2010 in the EU were 22.4% higher (full line) and 13.9% higher in Croatia (dash line). The natural gas prices over the same period increased by 13% in the EU and decreased by 3.9% in Croatia. The natural gas price for household consumers in Croatia is one of the lowest in the whole EU (the third lowest after Romania and Hungary in 2018). The real GDP per capita, presented in Fig. 1c, has been growing steadily both for the EU and Croatia, 10.9% and 14.2%, respectively. Positive economic trends and energy efficiency policies at the EU level have resulted in decreasing the number of people at risk of poverty and social exclusion (Fig. 1d), despite generally increasing energy prices. The value of the indicator dropped for 8% in the EU and 20.3% in Croatia in the period 2010–2018.

Fig. 2 presents trends for four indicators from the European Union statistics on income and living conditions (EU-SILC) survey (European Commission, 2020):

a) Housing cost overburden rate, defined as the percentage of the population spending more than 40% of disposable household income on the housing costs,
b) The total population living in a dwelling with a leaking roof, damp walls, floors or foundation, or rot in window frames or floor,
c) Overcrowding rate, defined as the percentage of the people living in an overcrowded household which is defined with several criteria,
d) Arrears on utility bills.

All the observed income and living conditions indicators improved in the period 2010–2018, with higher improvement rates for Croatia in comparison to the EU average. The housing cost overburden rate (Fig. 2a) and the total population living in a dwelling with a leaking roof et al. (Fig. 2b) for Croatia dropped below the EU average at the beginning of the observed period and currently, Croatian citizens stand better than the EU average in these categories. However, the overcrowding rate in Croatia (Fig. 2c) is one of the highest in the European Union (the third highest after Romania and Bulgaria in 2018) and high above the EU average. Moreover, the percentage of the population with arrears on utility bills (Fig. 2d) is significantly higher than the EU average (also the third largest in the EU after Greece and Bulgaria in 2018), reflecting still much lower purchasing power of Croatian citizens. Despite the fact that

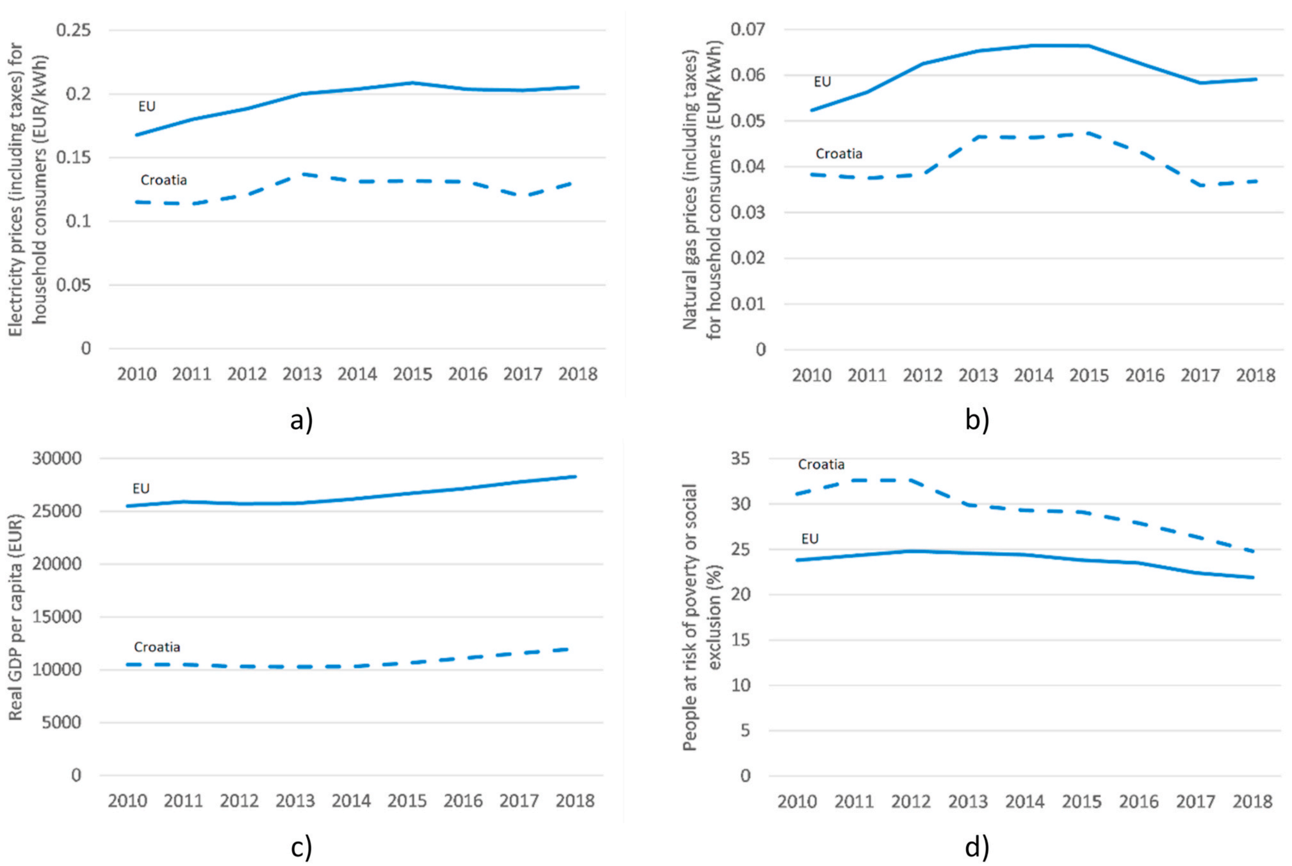

Fig. 1. Selected economic indicators for Croatia (dash line) and the EU average (full line) (European Commission, 2020).

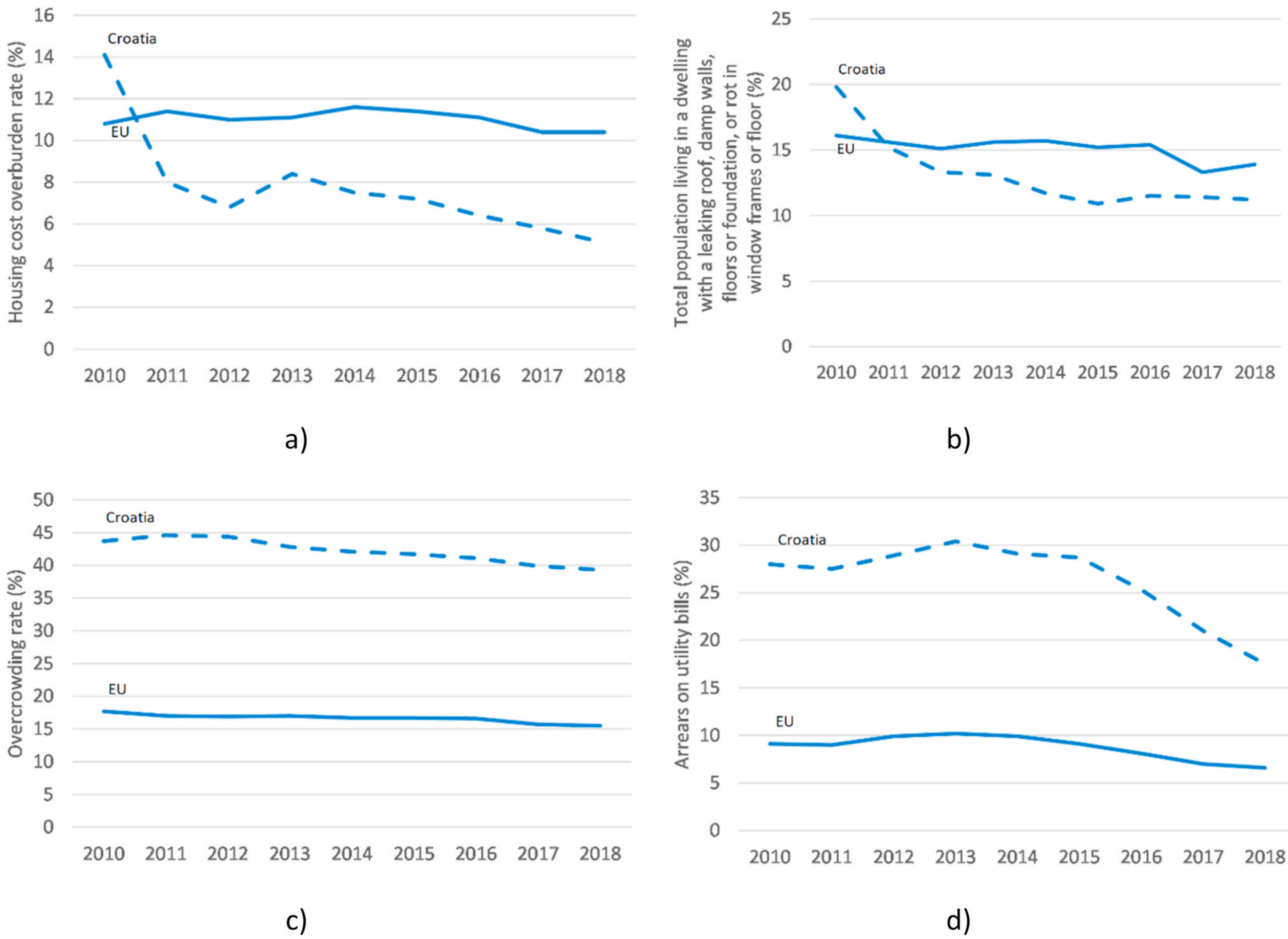

Fig. 2. Selected income and living conditions indicators for Croatia (dash line) and the EU average (full line) (European Commission, 2020).

most indicators for Croatia have improved over the last decade, it is evident that there is still a significant share of population suffering from living in overcrowded dwellings, with leaking roofs and being unable to pay their utility bills on time.

2.2. Legal framework

The energy poverty term and closely related phrase of a vulnerable consumer entered the Croatian legislation after the EU's "Third Energy Package" in 2009 (Robić and Ančić, 2018). Since then, it has been mentioned in many legislative documents – ranging from strategies to by-law decrees, and it is mostly identified with economic poverty. The reasons for choosing the same vulnerable groups which are already recipients of some sort of social support are primarily of administrative nature – collecting new data is a complex and at times costly challenge. Currently, there are three direct payment measures in Croatia regulated mostly by The Social Welfare Act (Croatian parliament, 2019) and partly by The Energy Act (Croatian parliament, 2015):

- compensation for electricity costs for vulnerable energy consumers up to 200 HRK (26 EUR); the status of a vulnerable consumer can have recipients of guaranteed minimum compensation (social welfare) and/or disability support,
- compensation for heating costs for households which are recipients of guaranteed minimum compensation and which use fuelwood are entitled to 3 m^3 of wood for heating annually or the equivalent monetary value,
- compensation for living costs (utility bills) for households which are recipients of guaranteed minimum compensation in the amount up to 50% of the received minimum compensation (living costs include renting, heating, electricity, water and other utility costs); however, this compensation is reimbursed by the local authorities and depends on their financial capacity.

All three of these measures have only a limited impact, without a long-term improvement of living conditions and quality of life of (energy) poor households. However, adjustments have been made recently in "The program of energy renovation for single-family houses" where one-fifth of the allocated funds will be directed specifically to poor households, covering 100% of their investment in energy efficiency (Ministry of Construction and Physical Planning, 2020). Unfortunately, because of the limited budget, in the first phase of the measure execution, it will only be available to the most vulnerable ones – recipients of a guaranteed minimum compensation, equalizing once again energy poverty with general poverty. Finally, the creation, adoption, and implementation of "The program for energy poverty alleviation" is specified in the three strategic documents: "Proposal of the strategy of energy development of the Republic of Croatia by 2030, with a view to 2050" (Government of the Republic of Croatia, 2019), "The 4th National Energy Efficiency Action Plan (NEEAP, 2017–2019)" (Ministry of Environmental Protection and Energy, 2017), and "Integrated energy and climate action plan for the Republic of Croatia for the period from 2021 to 2030" (Ministry of Environmental Protection and Energy, 2019). The three main components of the program will be a unique model for cost compensation, energy consulting, and measures for energy renovation and improving energy efficiency in energy poor households. The execution of the announced "Program for energy poverty alleviation" is anticipated impatiently because the current Croatian policy affronting the issue of energy poverty is insufficient and unsystematic. The Program was already to be adopted and developed by the end of 2019; however, this has not yet been done.

3. Field visits

Recognizing the need for gathering evidence and providing much needed data on reality of energy poverty in Croatia to decision makers, survey was designed, and field visits were undertaken.

3.1. Description

Research data was collected in the City of Zagreb from January to July 2019 by students of Faculty of Electrical Engineering and Computing University of Zagreb who have undergone basic energy audit training and were acquainted with principals undertaking structured interviews/surveys. During visits to 102 vulnerable households, students also implemented simple and low-cost energy efficiency measures, such as LED bulbs, draught proofing of windows and doors, water-saving aerators, timers for electrical boilers etc. The list of 102 households was provided by the City of Zagreb, Office for social welfare and people with disabilities, and by local nongovernmental organizations working with different vulnerable groups such as pensioners, people with disabilities and users of social shops. All visited households are recipients of guaranteed minimum compensation and/or some other support provided by local NGOs.

Structured surveys consist of basic household and respondent demographic data, energy-related part, and health/social aspects. In each household, one household member was surveyed. Overall, the survey consisted of 29 questions and approximately students needed 30 min to examine and fill in the answers. All collected data has been used exclusively on the aggregated level, and according to the GDPR compliance. Survey was based on the previous research done in Croatia which were primarily focused on health issues (Robić and Ančić, 2018; Ančić et al., 2015). In this paper, energy-related aspects are the primary focus, including type, age, and the surface of a dwelling, wall and window materials and characteristics, insulation properties, heating systems and consumption, utility bills expenses, etc. Due to the limited time and equipment, only descriptive data on the wall materials and properties were collected.

3.2. Selected results

The selected socio-demographic characteristics of respondents are presented in Fig. 3. The largest age group consists of persons older than 65 years–38.2% (Fig. 3a), and two-thirds of all the respondents are older than 55 years. Women were more represented in comparison to men as can be observed in Fig. 3b, and this was especially emphasized in older age groups. Most of the respondents are pensioners - 54.9% (Fig. 3c) which is expected concerning the age structure. The second most represented "work status" group is the unemployed group with 21.6%, followed by the employed and the permanently sick or disabled group with an equal share of 8.8%. Regarding the education, most of the respondents, 55.9% of them have a secondary degree (Fig. 3d), tertiary degree have 21.6%, followed by respondents with an only primary degree – 15.6%, while 5.9% of them does not have any formal degree, i.e. they have not finished their primary education.

The selected characteristics of the visited dwellings are presented in Fig. 4. Most of the visited households are the owners of their dwelling –

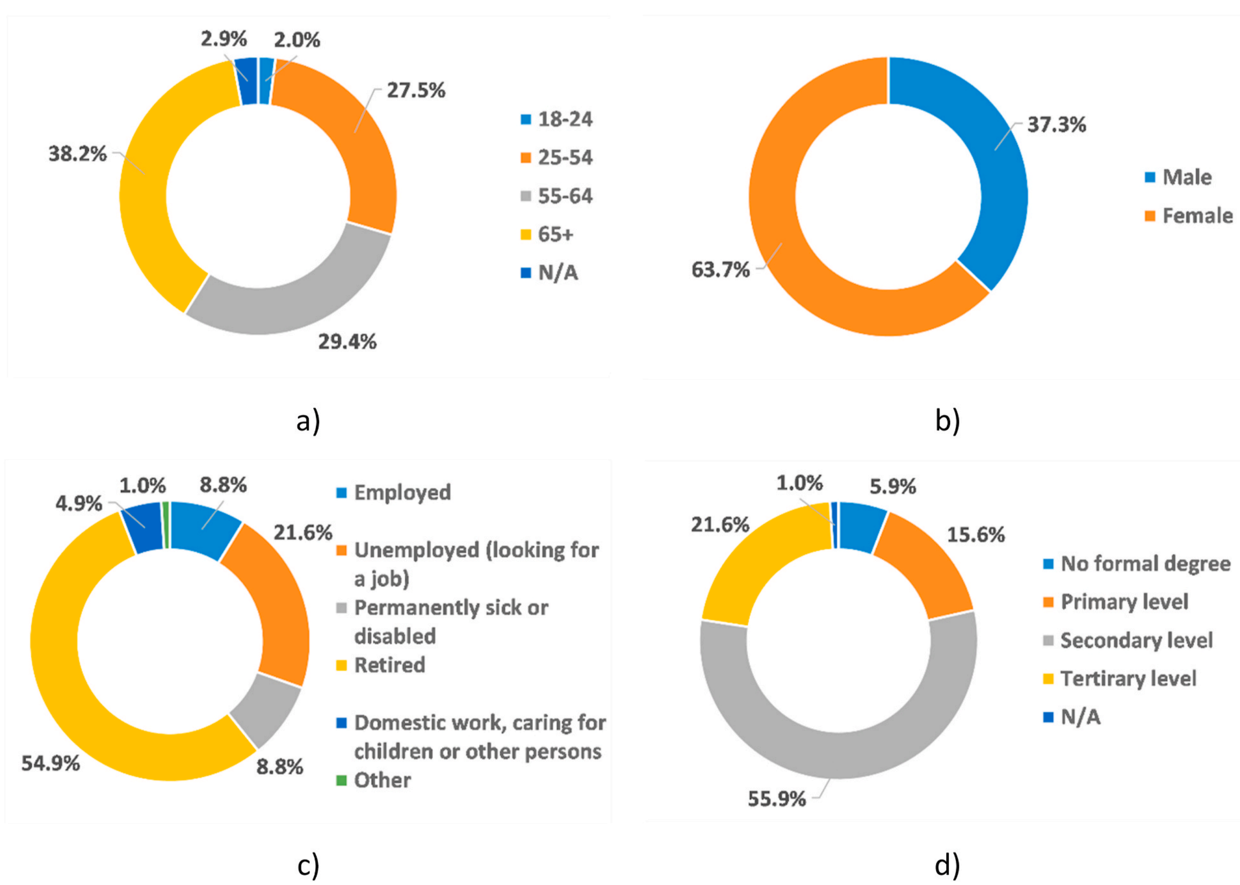

Fig. 3. Selected socio-demographic characteristics of respondents: a) age; b) sex; c) work status; d) education.

67.6% (Fig. 4a) but still much lower than the Croatian average of 90% (which is one of the highest in the EU). A higher share of the visited dwellings belongs to apartments – 57.8% (Fig. 4b), which is to be expected as it is an urban area, and most of the dwellings were built in the period from 25 to 60 years ago – 66.7% (Fig. 4c). Fig. 4d presents wall materials of the visited buildings. Full bricks are represented with 39.2%, hollow bricks 18.6%, wooden houses with 2% and other materials including reinforced concrete and concrete blocks have a share of 36.3%. Regarding the thermal characteristics of an outer envelope, most of the dwellings do not have any insulation (52.0%, Fig. 4e), and double-glazed windows without insulation are the most common type of windows (56.9%, Fig. 4f). Single-glazed windows still have a significant share of 12.7%. Most of the dwellings are connected to a district heating plant – 36.3%, or have a natural gas central heating system – 32.4%, as

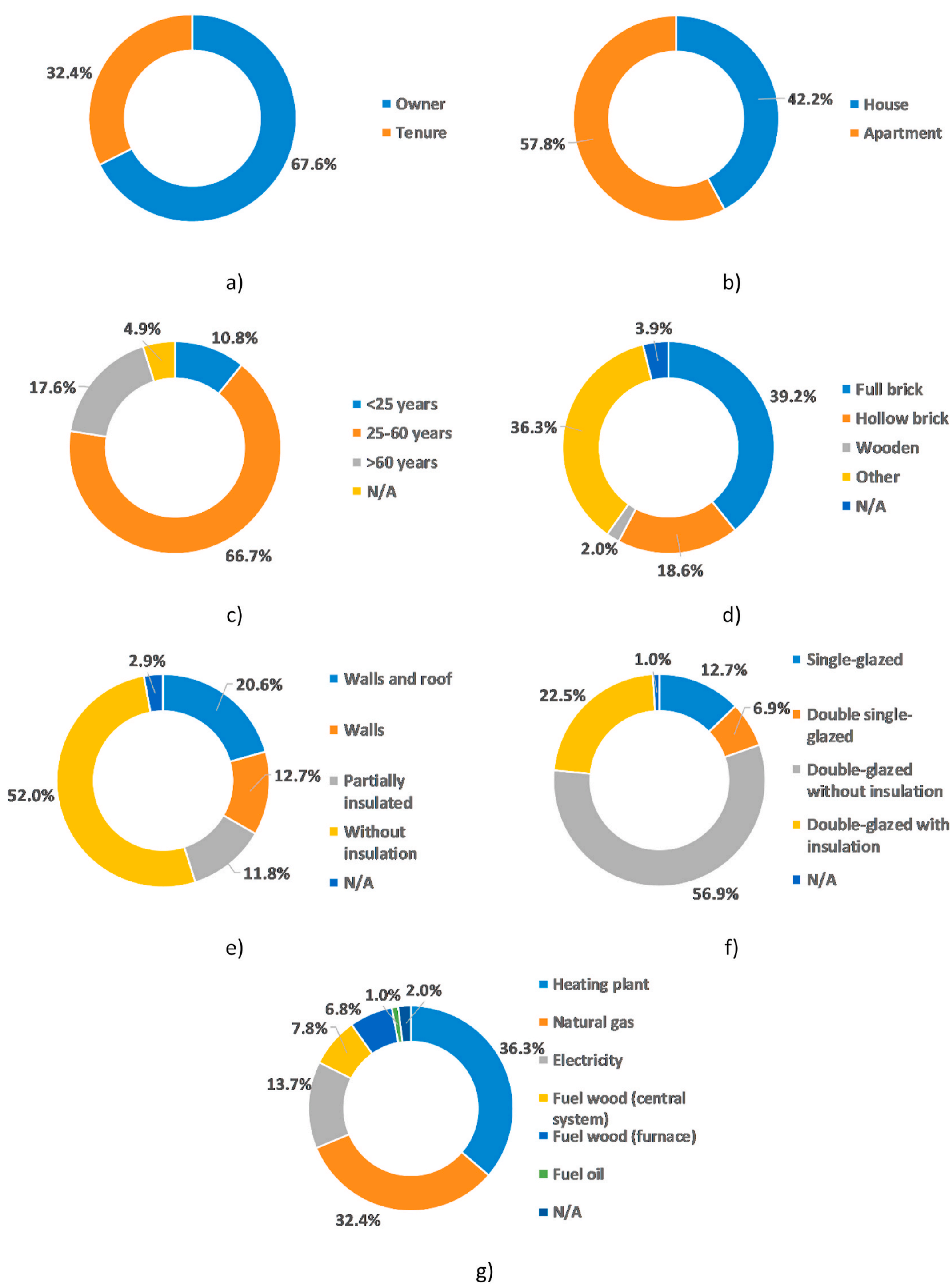

Fig. 4. Selected characteristics of the visited dwellings: a) ownership; b) type; c) age of construction; d) wall materials; e) building insulation; f) window type; g) heating system.

can be observed from Fig. 4g. Considerable 13.7% are heated with electricity, almost 15% are heated on fuelwood (of which more than half have central heating systems, and other have furnaces), and fuel oil is still represented as a heating fuel in one visited household.

In Fig. 5 the selected results from the questionnaire are presented, data on the living conditions and housing costs, as collected by students during the field visits. Remarkable 29.4% of respondents consider inside temperature to be too low during winter (Figs. 5a) and 52% are forced to reduce or turn-off heating in certain rooms, reducing thereby their living space in winter, because of financial reasons (Fig. 5b). More than half of surveyed respondents (54.9%) perceive draught through windows and mould is visible in 29.4% of households. In many visited households, windows and/or doors could not be adequately closed because of the wearing and deformities of frames, contributing to the draught feeling of the dwellers. Almost one-third of respondents have financial difficulties with all three utility bills (electricity, water, heating) as can be observed in Fig. 5c, while most of the respondents have difficulties with heating bills (41.2%).

3.3. Discussion of the survey

The analysis of the collected data suggests that all main three preconditions which cause the occurrence of energy poverty have been met: income, prices, and energy efficiency. From the socio-demographic perspective of the visited households, this is a significant share of older and retired residents which in general have lower than average income and spending most of the time at home. Moreover, the literature suggests that elderly people have higher heating expenditures, e.g. (Tonn and Eisenberg, 2007; Brounen et al., 2012). Furthermore, among this group, female singles are the most common, which also aggravates the issue since single-families have larger per-capita energy expenditures in comparison to families with two or more members. From the building's perspective, a high share of dwellings without any wall or window insulation indicates a poor energy efficiency of the visited households. The fact that half of the visited dwellings are heated either on electricity or heating plant is credited for the fulfillment of the third condition – prices. As will be discussed in the next chapter, the cost of these heating systems/fuels is significantly higher compared to natural gas or fuelwood. As a result, the fact that more than 50% of dwellers are unwillingly reducing heat during winter, is, unfortunately, a natural consequence of these conditions. Nevertheless, it is not even necessary that all three preconditions need to be satisfied to cause energy poverty – two of them in many circumstances could be enough.

4. Payback period of retrofitting building walls

As it was discussed throughout the introduction, energy poverty is to a large extent preconditioned by poor efficiency of dwellings. To understand the complexities of a living situation in energy aspects in the City of Zagreb, field data were collected and analyzed. To gain insights into potential benefits of energy efficiency retrofits focus was put on those visited dwellings without any or with partial thermal wall insulation which make a considerable 63.8% of the visited households (Fig. 4e). The payback period of walls retrofitting is calculated for overall N = 62 households which account for 60.8% of all the visited households, excluding those without necessary data being collected.

4.1. Calculation description and input data

The payback time of walls retrofitting is calculated according to the following formula:

$$\textit{Payback period}\,[\text{year}] = \frac{\textit{Investment}\,[\text{HRK}]}{\textit{Savings}\,[\text{HRK/year}]} \tag{1}$$

$$\textit{Payback period}\,[\text{year}] = \frac{\textit{Walls retrofitting}\,[\text{HRK/m}^2]\cdot \textit{Surface}\,[\text{m}^2]}{\textit{Heating savings}\,[\text{kWh/year}]\cdot \textit{Heating cost}\,[\text{HRK/kWh}]} \tag{2}$$

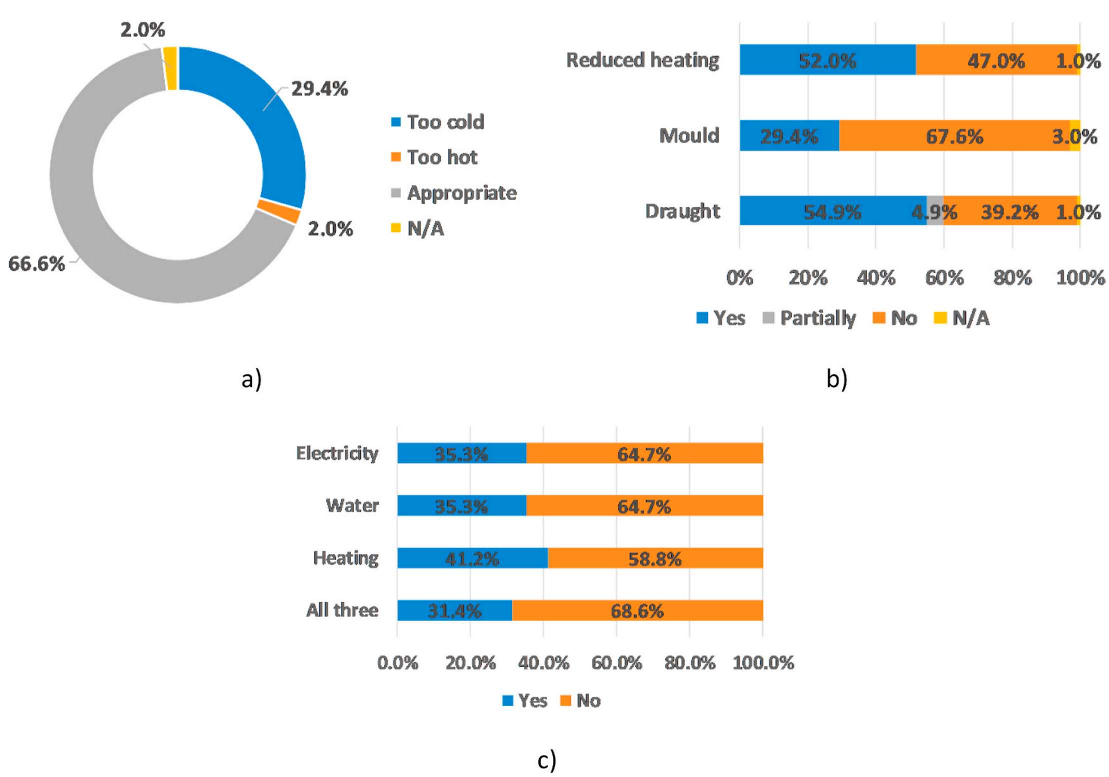

Fig. 5. The selected responses from the questionnaire: a) inside temperature satisfaction; b) reduced or turned-off heating in certain rooms (unwillingly), perception of draught through windows, and visible mould; c) financial difficulties with utility bills.

$$Payback\ period\ [\text{year}] = \frac{Walls\ retrofitting\ [\text{HRK/m}^2]\ \cdot Surface\ [\text{m}^2]}{\Delta k\ [\text{W/m}^2\text{K}]\cdot\sum_1^{8760}\Delta T\ [\text{K}]\cdot 1\ [\text{h}]\cdot\ Surface\ [\text{m}^2]\cdot Heating\ cost\ [\text{HRK/kWh}]} \tag{3}$$

$$Payback\ period\ [\text{year}] = \frac{Walls\ retrofitting\ [\text{HRK/m}^2]}{\Delta k\ [\text{W/m}^2\text{K}]\cdot\sum_1^{8760}\Delta T\ [\text{K}]\cdot 1\ [\text{h}]\cdot Heating\ cost\ [\text{HRK/kWh}]} \tag{4}$$

with $\Delta k = k_{before} - k_{after}$, where k_{before} and k_{after} are the heat transfer coefficients of walls before and after the retrofitting (without and with thermal insulation).

For all dwellings, the same retrofitting measure is considered – an external thermal insulation composite system (ETICS) with 8 cm thickness. The conservative cost of 200 HRK/m^2 (26 EUR/m^2) of such thermal insulation used currently in Croatia (EMAJSTOR, 2020) is chosen for the payback period calculation. Heating costs depend on the heating system of a dwelling. Five different heating systems are considered: district heating plant, natural gas, fuelwood, electricity, and fuel oil. Heating costs are specified in Table 1, together with fuel costs and efficiencies of different heating technologies.

The City of Zagreb is located in the continental part of Croatia (see Fig. 6), and according to the Köppen climate classification belongs to the Cfb category (Šegota and Filipčić, 2003), temperate oceanic climate without a dry season and warm summer. This information is relevant to the geographical dimension of energy poverty occurrence. For the calculation purposes, average air temperatures in Zagreb during 2018 with the hourly resolution are acquired by the courtesy of Croatian Meteorological and Hydrological Service (Fig. 7). It is assumed that the heating system is working maximally 14 h a day from 8 a.m. to 10 p.m., only if the outdoor air temperature is lower than 20 °C. From thus defined conditions results in 3153 heating hours in 2018 (36% of the time).

Lastly, heat transfer coefficients of walls are determined by considering wall materials, thickness, and age of dwelling construction. Since data acquisition in households were done by student volunteers who are not specially trained professionals, the values of heat transfer coefficients are taken as a range of values using the "Methodology for conducting energy audits of buildings" (Ministry of Construction and Physical Planning, 2017). Heat transfer coefficients of walls before and after retrofitting and for different wall materials are shown in Table 2. Because of the uncertainty in the wall material category "other" a larger range is considered. The conservative values of the payback period are obtained by using the lower values of ranges from the table. All households are finally categorized into 15 different groups regarding the heating system/fuel and wall materials.

Table 1
Heating costs for different technologies (HEP Elektra, 2020; HEP Plin, 2020).

Heating system	Fuel cost	Energy conversion	Efficiency	Heating cost
Heating plant	–	–	–	0.5 HRK/kWh
Natural gas	0.29 HRK/kWh	1	92%	0.315 HRK/kWh
Fuelwood	420 HRK/m^3	200 kWh/m^3	70%	0.3 HRK/kWh
Electricity	0.99 HRK/kWh	1	99%	1 HRK/kWh
Fuel oil	4.89 HRK/L	10 kWh/L	92%	0.532 HRK/kWh

4.2. Results and discussion

The number of households (without wall insulation considered in this calculation) by different heating systems and wall materials is presented in Fig. 8. The largest number of households are connected to a district heating plant and have walls built from other/concrete materials. Only one household uses fuel oil for heating. The number of households in categories: *Other/Fuel wood*, *Other/Fuel oil* and *Hollow brick/Fuel oil* is equal to zero.

The results of the payback period calculation for different heating systems and wall materials are presented in Fig. 9. For each category two values are calculated: the high or conservative (using lower values of heat transfer coefficients before retrofitting from Table 2), and the low (using higher values from Table 2). The lowest payback periods are obtained for dwellings heated on electricity (because of the highest heating energy cost of electricity, Table 1) and the highest payback periods are obtained for dwellings heated on fuelwood or natural gas and with walls built from hollow bricks (a combination of low heating energy cost and low heat transfer coefficient of walls before the retrofitting).

If the conservative values are considered, the following categories have the payback period lower than 10 years: *Fuel brick/Electricity*, *Hollow brick/Electricity*, *Other/Heating plant*, *Other/Electricity,* and *Other/Fuel Oil*. These households account for 40.3% of the observed households (25 out of 62). If the categories whose lower payback period is less than 10 years are also taken into account (*Full brick/Heating plant*, *Full brick/Fuel oil*, *Hollow brick/Heating plant*, *Hollow brick/Fuel oil*, *Other/Natural gas,* and *Other/Fuel wood*) the corresponding number of households with payback period lower than 10 years increases to 58.1% (36 out of 62).

These results confirm the cost-effectiveness of walls retrofitting as an energy efficiency measure which can ensure long-term energy savings and thus lower direct payments to vulnerable households provided by the local and national authorities. It needs to be emphasized that the calculated payback periods are to some degree underestimated because of the "prebound" effect. However, reflecting the high rates of the visited households in the City of Zagreb which reduce heating during the winter and with mould and draught difficulties, a positive impact of thermal retrofitting on living conditions and wellbeing of mostly socially vulnerable residents certainly offsets the difference between the calculated and accomplished energy savings.

Furthermore, if only the first group of households is considered, with the conservative payback period of walls retrofitting lower than 10 years, 72% of them live in an apartment dwelling and 44% are tenants which are significantly higher compared to the rates for all the visited households (57.8% of apartments and 32.4% of tenants in Fig. 4a and b). Higher apartment and tenure rates present a potential obstacle to the implementation of energy efficiency measures of retrofitting walls in dwellings with the lowest payback periods since landlords will likely not make long-term investments in rented dwellings, and measure of retrofitting walls is more difficult to conduct in apartment buildings in comparison to single-family houses. For these reasons, there is a necessity to adopt regulations that will restrict the renting of low energy-efficient dwellings.

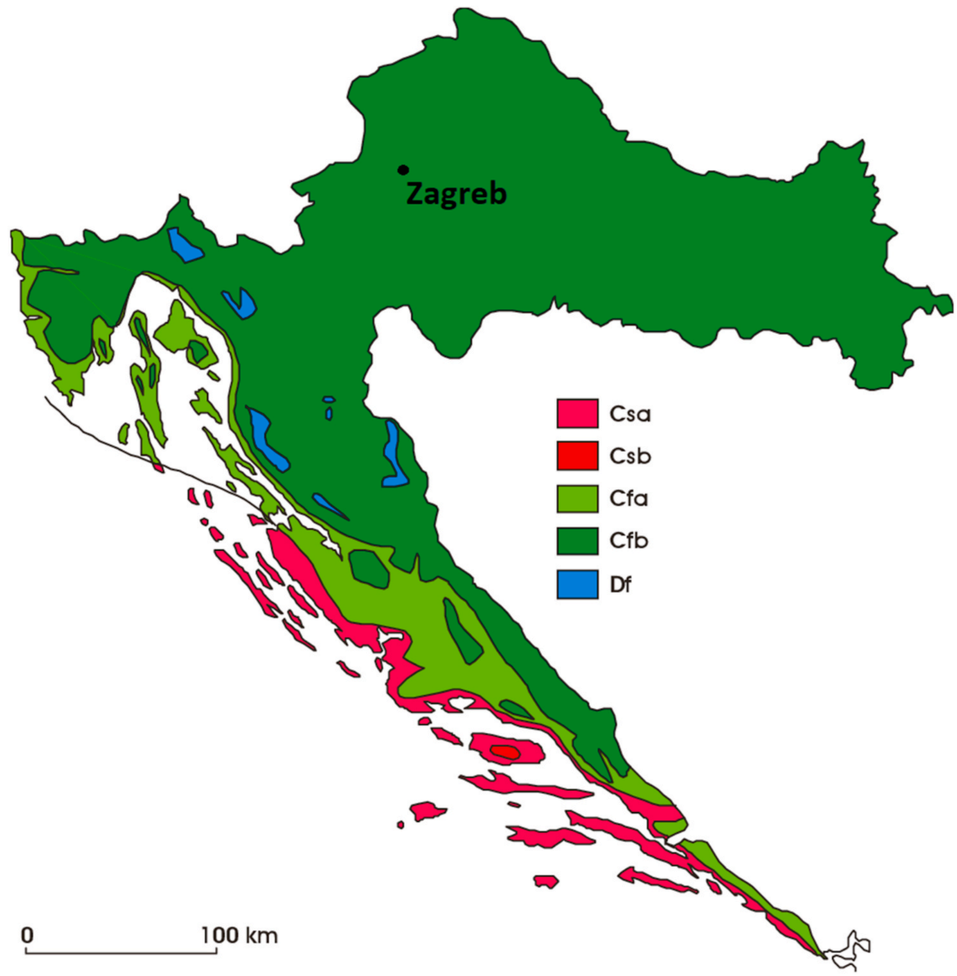

Fig. 6. Köppen climate classification in Croatia (Šegota and Filipčić, 2003).

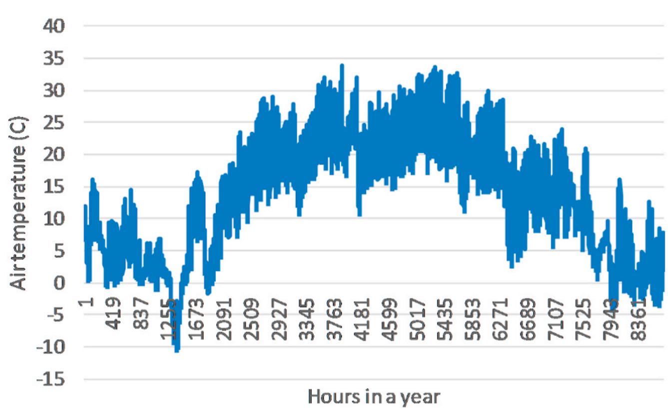

Fig. 7. Average air temperature in Zagreb during 2018 with the hourly resolution.

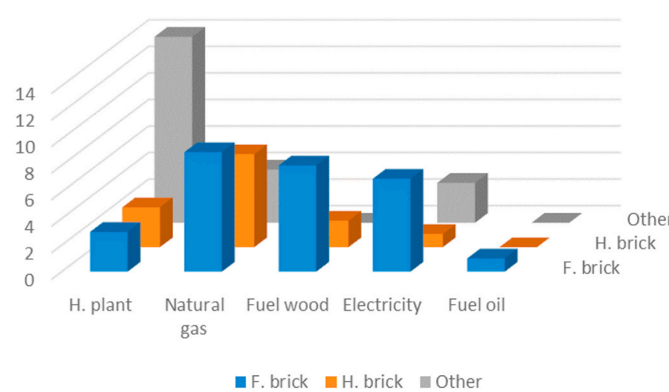

Fig. 8. Number of households by different heating systems and wall materials.

Table 2
Heat transfer coefficients of different wall materials (Ministry of Construction and Physical Planning, 2017).

Wall materials	Before retrofitting	After retrofitting
Full brick	1.4–1.89	0.38–0.41
Hollow brick	1.21–1.62	0.37–0.4
Other (reinforced concrete, concrete blocks)	1.61–2.65	0.4–0.45

5. Conclusion and policy implications

Existing policies in Croatia (and in most of the other countries) are focused on lowering the financial burden of (energy) poor households, without long-term improvement on living conditions and without removing some of the main causes of energy poverty. Therefore, in the creation of new policies, the delicate balance between direct financial payments for energy costs and investments in energy efficiency should be found. Since, at the moment, there are no systematic policies to alleviate energy poverty in Croatia, the announced "Program for energy poverty alleviation" is expected impatiently. Economic and living

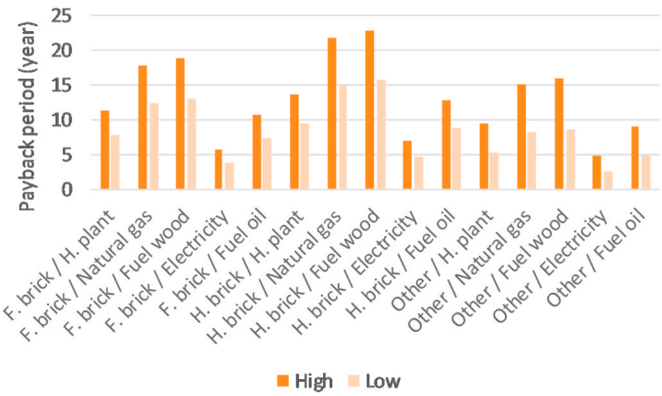

Fig. 9. Payback periods for different heating systems and wall materials.

conditions indicators in Croatia have improved significantly since entered the EU in 2013. Still, the share of people at risk of poverty or social exclusion is higher than the EU average. It is also notable, that the overcrowding rate in Croatia, the percentage of people living in an overcrowded household, is more than twofold than the EU average.

Within the project, "FER solutions for a better community" 102 poor households were visited in the City of Zagreb in which the simple energy efficiency measures were also conducted and the basic information on the dwelling characteristics and energy consumption was gathered. Most of the visited households live in buildings without any thermal insulation and a significant share is heated on electricity. More than one-half of the respondents perceive draught through doors and windows, more than one-half reduce or turn off the heating in certain rooms, and mould is visible in almost one-third of the visited households. This data gathered during the field visits shows poor living and energy conditions in the visited households.

The calculation of the payback period of walls retrofitting first showed that between 40.3 and 58.1% of poor households without wall insulation in the city of Zagreb has the payback period lower than 10 years, making the walls retrofitting financial competitive and cost-effective energy efficiency option. Retrofitting buildings have a long-term effect on systematically decreasing energy consumption and related expenses, decreasing greenhouse gas emissions and stimulating the local economy. Moreover, it contributes to the improvement of living conditions, and consequently on the health of household members. Second, it was showed that among these high-intensity energy households, there is a higher share of rented apartments compared to all the visited households. A lot of buildings with poor energy-efficiency are on the renting market which should facilitate the adoption of rental ban regulations of such dwellings.

CRediT authorship contribution statement

Goran Grdenić: All the authors jointly contributed to the design and implementation of the research, to the analysis of the results and to the writing of the manuscript. **Marko Delimar:** All the authors jointly contributed to the design and implementation of the research, to the analysis of the results and to the writing of the manuscript. **Slavica Robić:** All the authors jointly contributed to the design and implementation of the research, to the analysis of the results and to the writing of the manuscript.

Declaration of competing interest

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

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References

Ančić, B., Domazet, M., Grbavac, K., 2015. Istraživački Izvještaj O Energetskom Siromaštvu U Petrinji. Institut za društvena istraživanja, Zagreb.
Besagni, G., Borgarello, M., 2018. The determinants of residential energy expenditure in Italy. Energy 165, 369–386.
Besagni, G., Borgarello, M., 2019. The socio-demographic and geographical dimensions of fuel poverty in Italy. Energy Res. Soc. Sci. 49, 192–203.
Boardman, B., 1991. Fuel Poverty: from Cold Homes to Affordable Warmth. Belhaven Press, London.
Boardman, B., 2012. Fuel poverty sythesis: lessons learnt, actions needed. Energy Pol. 49, 143–148.
Bouzarovski, S., Saska, P., Sarlamanov, R., 2012. Energy poverty policies in the EU: a critical perspective. Energy Pol. 49, 76–82.
Brounen, D., Kok, N., Quigley, J.M., 2012. Residential energy use and conservation: economics and demographics. Eur. Econ. Rev. 56, 931–945.
Burlinson, A., Giulietti, M., Battisti, G., 2018. The elephant in the energy room: establishing the nexus between housing poverty and fuel poverty. Energy Econ. 72, 135–144.
Capdevila, I., Linares, E., Folch, R., 2012. Eficiencia energetica en la rehabilitacion de edificios. Fundacion Gas Natural Fenosa, Barcelona.
Croatian parliament, 2015. The Energy Act. Narodne novine, Zagreb.
Croatian parliament, 2019. The Social Welfare Act. Narodne novine, Zagreb.
Dubois, U., Meier, H., 2016. Energy affordability and energy inequality in Europe: implications for policymaking. Energy Res. Soc. Sci. 18, 21–35.
E4The Future, 2016. Occupant health benefits of residential energy efficiency. Framingham: E4The Future.
Elektra, H.E.P., 2020. Electricity prices [Online] Available at: http://www.hep.hr/elektra/kucanstvo/tarifne-stavke-cijene/1547. (Accessed 5 March 2020).
EMAJSTOR, 2020. Thermal insulation prices [Online] Available at: https://www.emajstor.hr/cijene/fasade. (Accessed 5 March 2020).
European Commission, 2011. Energy Efficiency Plan 2011. European Commission, Brussels.
European Commission, 2020. Eurostat [Online] Available at: https://ec.europa.eu/eurostat. (Accessed 13 February 2020).
Frieden, T.R., 2010. A framework for public health action: the health impact pyramid. Am. J. Publ. Health 100, 590–595.
Galvin, R., Sunikka-Blank, M., 2013. Economic viability in thermal retrofit policies: learning from ten years of experience in Germany. Energy Pol. 54, 343–351.
Government of the Republic of Croatia, 2019. Proposal of the Strategy of Energy Development of the Republic of Croatia by 2030, with a View to 2050. Government of the Republic of Croatia, Zagreb.
Großmann, K., et al., 2014. Energetische sanierung: sozialräumliche strukturen von Städten berücksichtigen. *GAIA,* Issue 23/4, 309–312.
Heffner, G., Campbell, N., 2011. *Evaluating The Co-benefits of Low-Income Energy-Efficiency Programmes,* s.L. International Energy Agency.
HEP, Plin, 2020. Natural gas prices for household consumers [Online] Available at: https://www.hep.hr/plin/cijene-plina-i-usluga/cijene-plina/cijene-plina-za-kucanstva/1620. (Accessed 5 March 2020).
Hills, J., 2012. Getting the Measure of Fuel Poverty. Crown copyright, London.
Hough, D., White, E., 2014. House of commons library [Online] Available at: https://researchbriefings.files.parliament.uk/documents/SN05763/SN05763.pdf. (Accessed 29 July 2020).
Li, K., LLoyd, B., Liang, X.-J., Wei, Y.-M., 2014. Energy poor or fuel poor: what are the differences? Energy Pol. 68, 476–481.
Longhi, S., 2015. Residential energy expenditures and the relevance of changes in houshold circumstances. Energy Econ. 49, 440–450.
Marmot Review Team, Friends of the Earth, 2011. The Health Impacts of Cold Homes and Fuel Poverty. Friends of the Earth & the Marmot Review Team, London.
Michelsen, C., Muller-Michelsen, S., 2010. Energieeffizienz im Altbau: Werden die Sanierungspotenziale überschätzt? Ergebnisse auf Grundlage des ista-IWH-Energieeffizienzindex, vol. 16. Wirtschaft im Wandel, pp. 447–455.
Ministry of Construction and Physical Planning, 2017. Methodology for Conducting Energy Audits of Buildings. Government of the Republic of Croatia, Zagreb.

Ministry of Construction and Physical Planning, 2020. Energy renewal of single-family houses [Online] Available at: https://mgipu.gov.hr/o-ministarstvu-15/djelokrug/energetska-ucinkovitost-u-zgradarstvu/energetska-obnova-zgrada-8321/energetska-obnova-obiteljskih-kuca-8324/8324. (Accessed 19 February 2020).
Ministry of Environmental Protection and Energy, 2017. The 4th National Energy Efficiency Action Plan (NEEAP, 2017-2019). Government of the Republic of Croatia, Zagreb.
Ministry of Environmental Protection and Energy, 2019. Integrated Energy and Climate Action Plan for the Republic of Croatia for the Period from 2021 to 2030. Government of the Republic of Croatia, Zagreb.
Moore, R., 2012. Definitions of fuel poverty: implications for policy. Energy Pol. 49, 19–26.
Ortiz, J., Casquero-Modrego, N., Salom, J., 2019. Health and related economic effects of residential energy retrofitting in Spain. Energy Pol. 130, 375–388.
Recalde, M., et al., 2019. Structural energy poverty vulnerability and excess winter mortality in the European Union: exploring the association between structural determinants and health. Energy Pol. 133, 110869.
Rehdanz, K., 2007. Determinants of residential space heating expenditures in Germany. Energy Econ. 29, 167–182.
Robić, S., 2016. Energy Poverty in Southeast Europe: Surviving the Cold. SEE Change Net, Sarajevo.
Robić, S., Ančić, B., 2018. Exploring health impacts of living in energy poverty: case study Sisak-Moslavina County, Croatia. Energy Build. 169, 379–387.
Robinson, C., Bouzarovski, S., Lindley, S., 2018. 'Getting the measure of fuel poverty': the geography of fuel poverty indicators in England. Energy Res. Soc. Sci. 36, 79–93.
Romero Rodríguez, L., et al., 2018. Mitigating energy poverty: potential contributions of combining PV and building thermal mass storage in low-income households. Energy Convers. Manag. 173, 65–80.
Šegota, T., Filipčić, A., 2003. Koppenova podjela klima i hrvatsko nazivlje. *Geoadria,* Issue 8/1, 17–37.
Society for Sustainable Development Design, 2020. FER solutions for a better community [Online] Available at: https://door.hr/portfolio/fer-rjesenja-za-bolju-zajednicu/. (Accessed 17 February 2020).
Tonn, B., Eisenberg, J., 2007. The aging US population and residential energy demand. Energy Pol. 35, 743–745.
Wolff, A., Schubert, J., Gill, B., 2017. Risiko energetische sanierung? In: Großmann, K., Schaffrin, A., Smigiel, C. (Eds.), Energie und soziale Ungleichheit. Springer VS, Weisbaden, pp. 611–634.