Climate justice: air quality and transitions from solid fuel heating

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Abstract

Of all the European Union’s member states, Poland has the most acute ambient air pollution problem. An urgent transition from solid-fuel heating (e.g. coal and wood) in the housing sector is required to improve air quality in the country. National regulations still allow the sale of solid fuels for heating, but some municipalities impose local resolutions with binding deadlines for solid-fuel bans. A real-world study covering 422 apartments in heritage tenements in Wrocław is presented. A link between domestic solid-fuel usage and tenure type is identified: solid fuels prevail in social housing. The transition to other forms of heating will adversely affect the inhabitants already vulnerable to fuel poverty. Solid fuel proves to be the least preferred heating option and is linked to substandard living conditions. Fuel poverty vulnerability for low-income households is established based on cost analysis for different heating options, thermal retrofit strategies, internal temperatures and apartment sizes. The results indicate that climate injustice is likely to occur for the poorest inhabitants due to their inability to afford increased costs. Policy implications to address this injustice are needed to ensure the transition from solid-fuel heating will avoid new vulnerabilities.

Policy relevance

Domestic solid-fuel combustion for heating purposes is linked to poor air quality in urban areas in Poland. Heritage tenements are the most technically deprived building stock and their inhabitants are already vulnerable to fuel poverty. To improve air quality and respond to climate change, solid fuels need to be substituted with less polluting but more expensive heating options. Potential climate injustice (harm) is likely to occur if the poorest inhabitants cannot afford to heat their homes due to a ban on solid fuels. The change of heating needs to be combined with additional support (thermal retrofit and appropriate pricing of alternative fuels). Air quality-driven policies focused on solid-fuel eradication should not ignore fuel poverty already experienced mainly by social housing residents using expensive electric heating on a standard tariff. Fuel poverty has a gender aspect related to the gender pay gap that needs addressing.

Keywords: built environment; climate justice; fuel poverty; housing; poverty; retrofit; space heating; vulnerability; Poland

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1. Introduction

The Intergovernmental Panel on Climate Change (IPCC) reported that CO₂ emissions need to be reduced by 45% by 2030 to keep the rise in global temperatures under 1.5°C (IPCC 2019). The effective implementation of climate polices is crucial in achieving this goal (Perrissin Fabert et al. 2014). The concept of climate justice entails the protection of populations made vulnerable by climate change impacts, especially due to the differential between those causing and experiencing the impacts (Shue 2016). The protection involves the sharing of burdens related to climate policies based on equity and the historical share in anthropogenic greenhouse gas emissions. At an international level, this means policy can act as a means of corrective justice. Weighted policy burdens have the potential to redress past uneven growth and lessen the strain on the already disadvantaged economies to increase their chances for future prosperity.

Fuel poverty is caused by complex interactions between low income, high energy demand and cost (Boardman 1991). It leads to an economic and emotional struggle that affects people’s everyday life (Longhurst & Hargreaves 2019). Climate policy leading to fuel poverty, that is, insufficient access to energy services perceived as a necessary good, would warrant a call for climate justice (Lambie-Mumford & Snell 2015; Meier, Jamasb, & Orea 2013). The risk of the negative distributional consequences of the transition from solid fuel and the deepening of the inequality between low- and high-income households (Schulte & Heindl 2017) requires country-specific analyses to inform local policies (Löschel 2015). This is an urgent knowledge gap given the scale of the solid-fuel challenge.

At a global level, nearly 3 billion people rely on solid fuel to meet their household energy needs, mainly cooking and heating (WHO 2006). Most of the domestic solid-fuel combustion happens in developing countries and is linked to poverty. Solid fuel is used also across European Union (EU) households. Germany alone has 11 million stoves and boilers that use solid fuel (Rippl 2018). In Hungary, the proportion of households relying on solid fuels rose from 14% in 2005 to 36% in 2011 (Bouzarovski et al. 2016). The increase in solid-fuel usage enabled households to evade fuel poverty (Bouzarovski, Petrova, & Sarlamanov 2012) caused by the growing prices of other energy sources (Bosch et al. 2019). Fuel poverty is a significant problem in Europe (Bosch et al. 2019), and so are the emissions from solid-fuel burning linked to adverse health effects (Naeher et al. 2007).

Air pollution from particulate matter causes approximately 400,000 premature deaths in Europe annually (EEA 2019), and adds to the economic costs projected to reach about 2% of European gross domestic product (GDP) in 2060 (OECD 2016). To tackle air pollution, EU member states agreed on an Ambient Air Quality Directive (EU 2004, 2008) that sets binding standards for fine particles PM₁₀, as well as air quality measurement and reporting procedures. The data accumulated as a result of the Directive indicates continuous uneven distribution of the challenge across member states (EEA 2019).

The highest ambient air pollution in the heating season is recorded in urban areas in Eastern Europe, in particular in Bulgaria and Poland. In 2018, over 70% of the total final energy demand derived from solid fossil fuel in EU-28 countries was consumed by Polish households (Eurostat 2017). Although the share of solid fossil fuel in households’ energy portfolio dropped by over 40% between 2007 and 2017 within the Eurozone’s 19 countries, it remained stable in Poland. Domestic solid-fuel combustion for heating purposes is recognised as the main contributor to air pollution: ‘While constituting about 2.6% of total energy consumption in the EU, solid fuel combustion in households contributes more than 46% to total emissions of fine particulate matter, that is, three times more than road transport’ (Wolters 2018).

Several key questions arise:

- Can vulnerable populations be linked to solid-fuel heating?
- How will they be affected by the transition process to alternative, cleaner forms of space heating?
- Will the transition contribute to an increased fuel poverty vulnerability and limited capabilities (Sen 1980) of those currently disadvantaged?

This paper conceptualises climate justice on a micro-scale of policy burdens. The focus is on lowering the emissions caused by domestic heating, specifically in the transition away from solid fuels. Climate policies explicitly aim to stop burning coal; however, wood-burning also contributes to warming the climate through the black carbon component of fine particulate matter PM₁₀ (Robinson 2014).

This paper addresses the question: To what extent does the policy and planning transition away from solid fuel account for the avoidance of imposing injustices? The findings are based on a real-world study in one of major cities in Poland. The study surveyed 422 households in a central urban quarter in order to understand the key characteristics of the building stock, heating systems, tenure type and user feedback related to heating, thermal comfort and moisture experiences. These data informed modelling that explored the fuel poverty vulnerability associated with different fuels, income levels and building energy standards. Findings from the modelling reveal the potential risks or benefits of transition from solid fuel, depending on what alternative heating option is selected.

The paper is structured as follows. Next, the background of the air-quality challenge in Poland and the national and local legal context of domestic solid-fuel combustion are introduced. The characteristics of the urban quarter selected for the study are then presented. The methods section is followed by the findings of the field study. These are
followed by an analysis of the fuel poverty vulnerability related to different heating systems for the most vulnerable households. The discussion contextualises the findings in the air-quality and climate change policy related to the fuel poverty discourse. The limitations of the study are then explained. Further research needs and key policy implications are described in the conclusions.

2. Background

2.1. Air pollution policy

The World Health Organization (WHO) reported that that six out of the top 10 and 33 out of the top 50 European cities for ambient air pollution levels are in Poland (WHO 2006). During a smog episode in January 2017, nearly all cities in Poland issued smog alerts (meaning 300 μg/m³ PM₁₀ levels were exceeded) (Kobus, Nych, & Sówka 2018) and daily concentrations of PM₁₀ in Rybnik reached 1600 μg/m³, which is a 32-fold exceedance of the standard daily threshold of 50 μg/m³ (Durka, Kaminski, & Struzewska 2017). The Polish Ministry of Entrepreneurship and Technology (2018) reported that, in 2016, the air pollution from solid-fuel combustion caused 18,990 premature deaths, and that the estimated health cost for the country reached €30 billion.

In February 2018, that is, a decade after the Clean Air Directive was introduced, the EU Court of Justice ruled that 'Poland has infringed air quality laws' and it urged the Polish government to comply ‘without delay’ or face fines after finding that the country had regularly exceeded fine particle limits for years (Ward 2018). The top-down urge to demonstrate meeting the air-quality standards comes simultaneously with only a recent major policy shift at the level of local urban and regional authorities in Poland (Koźek & Szymański 2018). The amendment to national law (2017) allowed local authorities to establish regional restrictions in domestic solid-fuel combustion for heating purposes (Górka, Luszczyk, & Thier 2018).

In 2016, Krakow was the first, and so far the only, municipality in the country to announce a ban on domestic solid-fuel combustion, starting 1 September 2019. The ban goes further than the current EU policy that allows domestic solid-fuel combustion in ecolabel-compliant stoves or boilers (consumer.org 2019). Despite an information campaign, investment cost subsidies and policy to cover the increase in heating cost an estimated 4000 households in Kraków did not respond to the incentives or threats and still rely on solid fuel for heating. These households are at high risk of repeated fines. Crucially, they present a challenge for the municipality to achieve its clean air goal (O’Sullivan 2019). The inability to deactivate the polluting heating systems in the target group, despite the financial capacity to support the transition, suggests a gap between the incentives offered and the capacity or the will to respond to them. Most municipalities across Poland (unlike Kraków, Wrocław or Katowice) only subsidise the investment in heating system exchange, but do not provide compensation for the increased operational heating costs (Ogniewska-Rejer 2019). Thus, the uptake of cleaner heating technologies in most municipalities is even less than in Kraków. In Warsaw, where only the investment cost of changing the heating system was subsidised, only 1% of the budget allocated to that cause was spent in the first half of 2019 (Morawski & Siergiej 2019). An analysis of the effectiveness of local policies aiming to improve air quality covering the period 2014–17 revealed that if the five regions most advanced in introducing clean air policies maintained their current pace of change, it would take them between 24 and 99 years to comply with the air quality standards (Polish National Supreme Chamber of Control 2018).

It is clear that the actions undertaken neither by the national government nor by the local authorities are effective. A major gap exists in understanding the underlying causes of the slow progress in reducing solid-fuel-based heating systems in Poland. The European Social Survey (ESS), representative for all persons aged 15 years and over, related to societal attitudes towards energy and climate change, indicates that Poles are not very concerned about the country’s dependency on fossil fuels: 1% are extremely worried, 17% are very worried and 44% are somewhat worried (Pohjoilainen et al. 2018). Social attitudes might partly explain the problem, but there is also a link between actual behaviours and a lack of agency. Understanding the deeper context of the heating options available and practices related to heating are needed. So far, only statistical data are available on the country’s poverty, housing deprivation and fuel poverty estimates (EU Energy Poverty Observatory 2018; Lewandowski, Kiełczewska, & Ziółkowska 2018). Few studies to date have explored the transition of domestic heating from the affected households’ perspective, though there is some evidence of a low carbon gentrification risk (Bouzarovski, Frankowski, & Tirado Herrero 2018). Low carbon gentrification occurs when one socioeconomic group of inhabitants is displaced by another because of increased energy costs (capital or operating expenses). In order to foster the process of change without harm to the most vulnerable part of the population, this gap in fuel poverty understanding needs to be filled urgently.

2.2. The decarbonisation challenge

The EU decarbonisation strategy is challenging for Poland (Ancygię 2013). As in other Central and Eastern European (CEE) countries, the history of decarbonisation is much shorter than in Western and Northern Europe (Horak 2001). In the early 1990s, in both Poland and Czechia, the rise of public interest in environmental issues quickly shifted to other concerns involving the transition to a market economy and disappeared from the political discourse until the countries joined the EU (Horak 2001). After accession to the EU in 2004, environmental policy was perceived as an
obligation that could be addressed with minimal effort (Guttenbrunner 2009). In 2008, the Visegrad group jointly declared that the EU should refrain from solutions that neglected the differences in the economic potential of its member states (Jankowska 2010). In 2019, Poland, Czechia, Hungary and Estonia blocked the EU 2050 carbon-neutral target (Krukowska 2019). Poland’s explicit government strategy for 2040 is to continue its reliance on coal for electricity and heat in district heating (Polish Ministry of Energy 2019). Such a stance is justified by a narrow conceptualisation of energy security understood as access to fuel (Sovacool 2016). The Polish national government stated that it intends to tackle solid-fuel combustion for heating purposes which is present in 45.4% of Polish homes (Polish Central Statistical Office 2019; Polish Ministry of Energy 2019). However, this intention is not supported by the recently introduced national-level regulation of the quality of coal available to individual consumers (Polish Ministry of Energy 2018). The technical specification of the fuels allowed for sale was criticised for preserving the status quo they were meant to tackle, that is, the availability of coal sludge and floto-concentrates, that cause most pollution. Also, a national subsidies programme ‘Clean Air’, launched in 2018 to diminish or eliminate heating-related emissions from single-family houses, was criticised for supporting the replacement of old, inefficient solid-fuel stoves with new, efficient boilers that still use solid fuel. The government fossil fuel stance is challenged by some of the regional or municipality level regulations (Stala-Szlugaj 2018) driven by concerns about air pollution.

3. Wrocław: case study context

3.1. Local solid-fuel policy

Wrocław is a city in western Poland with over 660,000 inhabitants. The city ran a subsidies programme Kawka, before accepting the binding regional deadline of 2024 for banning domestic solid-fuel heating in stoves and boilers deemed inefficient. Since 2015, Kawka covered up to 100% of the cost (for equipment and its installation) of the transition away from solid fuel in tenements and single-family houses. A few years into the programme it became clear that the transition did not occur quickly enough. In 2020, the city introduced a novel incentives programme called ‘Change the Stove’ (zmienpiec.pl) targeting, in particular, social housing residents in mixed-tenure tenements (Figure 1). The programme strongly incentivises individual households to change their heating system by covering not only the investment costs and the increased cost in utility bills but also three years of free rent. However, the only thermal retrofit measure proposed is the replacement of draughty windows with energy-efficient ones. A different strategy is planned for the 100% municipality-owned tenements. These dwellings will be thermally retrofitted and connected to the district heating.

3.2. Tenement apartments: The historical context

Wrocław was over 80% destroyed during the Second World War. The city’s post-war population was migrants forced to leave their homes in the eastern part of pre-war Poland, whereas the city’s previous German population was forced to migrate west because of the changed national borders. The majority of the surviving tenements built at the turn of the 19th and 20th centuries became municipality owned. They are the key urban apartment block typology still heated through solid-fuel combustion. The original design of the tenements had a portfolio of apartments of different standards and size, most cross-ventilated, of about 80–120 m², with solid-fuel tiled stoves (Figure 2) in the main rooms as well as a solid-fuel kitchen stove. These apartments were subdivided post-war through minimum intervention, but there was the introduction of division walls (Figure 3). As a result, some apartments had access to stove kitchens while others did not; some rooms were heated and others were not. The toilets were usually located in the communal stairwell.

Figure 1: Street and backyard view of the tenements in Wrocław in the post- (left) and pre-retrofit (right) conditions.
4. Methods
A mixed-methods study covering a central urban quarter of 30 tenements in Wroclaw, previously reported (Baborska-Narozyń et al. 2018, 2019; Szulgowska-Zgrzywa et al. 2019), provided the empirical data. The study focused on the heating strategies deployed in 422 apartments in these buildings. The quarter (Figure 4) was designated for study by the funding body, that is, a city-owned enterprise Wroclawska Rewitalizacja (W-R; in English, Wroclaw Revitalization). W-R identified the quarter as one of the most deprived areas in the city and in need of a complex basket of revitalisation measures (involving technical, social and economic aspects). This was based on a multivariate analysis of the social and building stock characteristics of the whole city (Adamczyk-Arns et al. 2013).

The aim of the present study was twofold. First, it was methods orientated: to explore the different methods of data collection about the heating systems used in apartments of different ownership types. This aim related to designing a study in order to describe the distribution of different heating systems for the whole city. Second, it aimed to deliver quantitative and qualitative findings about the heating systems in use and the inhabitants’ perceptions with regard to heating in pre- or post-retrofit buildings (Table 1).

The analyses presented in this paper focus on three aspects:

- The link between the frequency of various heating systems, tenure types or household vulnerability.
- The housing standard associated with different heating systems.
- The impact of alternative heating system and tenement energy standards on fuel poverty vulnerability.

The mixed-methods study involved different types of data collected from different stakeholders (Table 2). The key data sources for the study were facility managers (FM), the inhabitants, site visits, utility providers and local social welfare centre (Miejski Ośrodek Pomocy Społecznej—MPOS, the Council Social Care Centre). The process of obtaining data relevant to the presented analyses is introduced below.
Figure 3: Original floor plan of a typical heritage tenement: pre-war layout (top) and post-war layout (bottom).

Figure 4: Characteristics of the urban quarter covered by the field study: building types and ownership structure.
Table 1: Characteristics of the analysed buildings based on data sets accessed or developed during this study.

| Building number | Construction year | Floors | Usable floor area of apts. (m²) | Apartments | Apartments' ownership type | Prevailing heating system | Building envelope energy standard (W/m²K) | Communal toilets in the stairwell |
|-----------------|------------------|--------|--------------------------------|------------|---------------------------|---------------------------|----------------------------------------|----------------------------------|
|                 |                  |        |                                |            | Private | Social | District heating | Solid fuel plus other | Walls | Roof | Windows |                                      |
| 1               | 1880             | 5      | 805                            | 15         | 7       | 8       | ×                |                                      | -0.87 | -0.84 | ~2.6–1.2 |                                      |
| 2               | 1880             | 5      | 434                            | 12         | 0       | 12      | ×                |                                      | -0.87 | -0.84 | ~2.6–1.2 | ×                                  |
| 3               | 1880             | 5      | 902                            | 18         | 10      | 8       | ×                |                                      | -0.87 | -0.84 | ~2.6–1.2 | ×                                  |
| 4               | 1904             | 5      | 778                            | 15         | 0       | 15      | ×                |                                      | -0.87 | -0.84 | ~2.6–1.2 | ×                                  |
| 5               | 1905             | 5      | 764                            | 19         | 8       | 11      | ×                |                                      | -0.87 | -0.84 | ~2.6–1.2 | ×                                  |
| 6               | 1993             | 6      | 668                            | 11         | 11      | 0       | ×                |                                      | -0.60 | -0.30 | ~2.0     |                                    |
| 7               | 1993             | 6      | 977                            | 17         | 17      | 0       | ×                |                                      | -0.60 | -0.30 | ~2.0     |                                    |
| 8               | 1880             | 5      | 619                            | 9          | 6       | 3       | ×                |                                      | -0.87 | -0.84 | ~2.6–1.2 |                                    |
| 9               | 1880             | 5      | 794                            | 19         | 0       | 19      | ×                |                                      | -0.87 | -0.84 | ~2.6–1.2 | ×                                  |
| 10              | 1880             | 5      | 676                            | 16         | 0       | 16      | ×                |                                      | -0.87 | -0.84 | ~2.6–1.2 | ×                                  |
| 11              | 1880             | 5      | 1017                           | 14         | 1       | 13      | ×                |                                      | -0.30 | -0.25 | ~1.7     | ×                                  |
| 12              | 1900             | 5      | 1116                           | 16         | 5       | 11      | ×                |                                      | -0.87 | -0.84 | ~2.6–1.2 |                                    |
| 13              | 1900             | 5      | 798                            | 15         | 0       | 15      | ×                |                                      | -0.87 | -0.84 | ~2.6–1.2 | ×                                  |
| 14              | 1900             | 5      | 799                            | 13         | 6       | 7       | ×                |                                      | -0.87 | -0.84 | ~2.6–1.2 | ×                                  |
| 15              | 1900             | 5      | 860                            | 15         | 6       | 9       | ×                |                                      | -0.87 | -0.84 | ~2.6–1.2 | ×                                  |
| 16              | 1900             | 5      | 887                            | 17         | 0       | 17      | ×                |                                      | -0.87 | -0.84 | ~2.6–1.2 | ×                                  |
| 17              | 1900             | 5      | 860                            | 13         | 7       | 6       | ×                |                                      | -0.87 | -0.84 | ~2.6–1.2 | ×                                  |
| 18              | 1889             | 5      | 1300                           | 18         | 8       | 10      | ×                |                                      | -0.87 | -0.84 | ~2.6–1.2 | ×                                  |
| 19              | 1900             | 5      | 964                            | 13         | 6       | 7       | ×                |                                      | -0.87 | -0.84 | ~2.6–1.2 |                                    |
| 20             | 1851             | 5      | No data                        | 58         | 58      | 0       | ×                |                                      | -0.23 | -0.18 | ~1.1     |                                    |
| 21              | 1900             | 5      | 917                            | 14         | 1       | 13      | ×                |                                      | -0.25 | -0.20 | ~1.3     |                                    |
| 22              | 1900             | 5      | 823                            | 17         | 0       | 17      | ×                |                                      | -0.87 | -0.84 | ~2.6–1.2 | ×                                  |
| 23              | 1890             | 5      | 661                            | 12         | 3       | 9       | ×                |                                      | -0.87 | -0.84 | ~2.6–1.2 | ×                                  |

(Contd.)
| Building number | Construction year | Floors | Usable floor area of apts. (m²) | Apartments | Apartments’ ownership type | Prevailing heating system | Building envelope energy standard (W/m²K) | Communal toilets in the stairwell |
|-----------------|-------------------|--------|---------------------------------|-----------|--------------------------|-------------------------|-------------------------------------|----------------------------------|
|                 |                   |        |                                 |           | Private | Social | District heating | Solid fuel plus other | Walls | Roof | Windows |                      |                                        |
| 24              | 1889              | 5      | 1084                            | 15        | 0       | 15     | ×                      |                                     | -0.87 | -0.25 | -2.6–1.2 |                                        |                                        |
| 25              | 1904              | 5      | 1226                            | 12        | 9       | 3      | ×                      |                                     | -0.87 | -0.84 | -2.6–1.2 |                                        |                                        |
| 26              | 1901              | 5      | 637                             | 12        | 1       | 11     | ×                      |                                     | -0.87 | -0.84 | -2.6–1.2 |                                        |                                        |
| 27              | 1900              | 5      | 562                             | 14        | 4       | 10     | ×                      |                                     | -0.87 | -0.84 | -2.6–1.2 |                                        | ×                                      |
| 28              | 1900              | 5      | 818                             | 18        | 6       | 12     | ×                      |                                     | -0.87 | -0.84 | -2.6–1.2 |                                        | ×                                      |
| 29              | 1900              | 5      | 725                             | 11        | 0       | 11     | ×                      |                                     | -0.87 | -0.84 | -2.6–1.2 |                                        |                                        |
| 30              | 1900              | 5      | 616                             | 12        | 0       | 12     | ×                      |                                     | -0.87 | -0.84 | -2.6–1.2 |                                        |                                        |
| **Total**       |                   |        |                                  |           |         |        |                       |                                      | 24,087 | 480   | 180   | 300            |                                        |                                        |

*Note:* Building excluded from home visits because of ongoing construction works.
Table 2: Data collection methods applied.

| Data-collection method       | Data source                              | Data type                              | Rationale for collecting                                                                 | Buildings/apartments with data obtained | Population size approached |
|------------------------------|------------------------------------------|----------------------------------------|----------------------------------------------------------------------------------------|-----------------------------------------|---------------------------|
| Walk through                 | Tenement                                  | Photographs, notes, sketches           | Understanding of the building, its spatial context, energy and technical standard plus apartment location in the building | 29/–                                    | 29/–                      |
|                              | Inhabitant plus apartment                 | Photographs, notes, sketches           | Type of heating system used plus fuel type and general standard (e.g. mould, location of heating sources or additional heaters) | –/54                                    | –/210                     |
| Mediated conversation        | Inhabitants                               | Detailed notes taken during and right after the conversation, digitised on the same day by the author of the notes | Inhabitant feedback on heating and hot water systems | 29/210<sup>a</sup>                      | 29/422                    |
| Access to a database         | Facility managers (FMs): municipal and private | Technical data about the building and apartment characteristics, ownership type, energy consumption for communal spaces | Understanding building stock characteristics, ownership structure, etc. | 9 FMs <sup>27/366<sup>b</sup></sup> | 11 FMs 29/422             |
|                              | Electricity providers                      | Monthly electricity consumption for each meter for one year | Validating inhabitants’ feedback and database content in relation to the heating systems used | 422                                      | 422                       |
|                              | District heating provider                  | Space heating and hot water (district heating) consumption data for tenement A | Validating inhabitants’ feedback and database content in relation to the heating systems used | 28                                       | 28                        |
| Assisted survey              | Special needs households through social workers | Paper survey with open questions | Feedback from the most vulnerable households | 20<sup>a</sup>                           | 20<sup>a</sup>             |
| Access to documents          | Municipal FM                              | Energy audit for tenement A            | Understanding the thermal retrofit scenarios considered by the municipality | 1                                        | 1                         |

Notes: <sup>a</sup>Paper questionnaire were distributed by social workers during their routine home visits to all special needs households within the studied quarter. <sup>b</sup>The inhabitant feedback and FMs’ data combined covered 390 apartments, that is, 92% of the studied population.
4.1. Facility managers (FMs)
Obtaining data from FMs required substantial effort related to collecting data manually from paper archives. Few FMs were able to provide the required data in digital form. Of 11 FMs responsible for the 29 studied buildings, two declined to participate. One of the municipal FMs shared a detailed energy audit (Standard Assessment Procedure (SAP) equivalent) analysing alternative scenarios of a planned thermal retrofit and change of heating system for one of the tenements. The retrofit scenarios and the resulting modelled heating demand were used for a preliminary analysis of the link between fuel poverty vulnerability for different sizes of apartments and different heating sources (see section 5.2).

4.2. Inhabitant feedback
Inhabitants’ feedback was of key importance as the scope of information sought was broader than routinely collected by FMs, that is, supplementary heating use, moisture and draught issues in the apartments, hot water source, inhabitant perception of the heating system used, and openness to change.

The studied urban quarter was diagnosed as a deprived area (Adamczyk-Arns et al. 2013). The assumption at the research design stage was that there would be a low level of trust among the inhabitants to open their doors, engage in a conversation and allow the researchers into their dwellings. A high response rate was sought rather than an in-depth account of a small sample when designing the research method for inhabitant feedback. Pragmatism, ethics and the safety of the process were the main guidelines. Ethical approval was to be sought, following the lead author’s experience of conducting fieldwork in a UK context (Baborska-Narozny 2017; Stevenson & Baborska-Narozny 2018). However, because of the unavailability of an ethical committee at the author’s academic institution and lack of responses from other institutions approached, no institutional consideration was possible. However, care was taken to follow the ethical academic standards at all stages of the research process (Sharpe 2019).

An information campaign preceded home visits to build awareness about all relevant aspects of the process. Posters were placed in the communal areas of each building. An information leaflet with all the key points about the study and further contact details were distributed to each dwelling’s post box. Four teams of four were formed for home visits planned for two consecutive weekends in January 2018. Home visits were scheduled for January, that is, the coldest month of the year (Figure 4) to observe the practices of the heating season. Each team consisted of an academic from the research team and three trained postgraduate students of architecture or mechanical engineering. Every group, with several addresses assigned, split in two when entering a building: one couple started from the ground floor, the other from the top floor to meet somewhere in the middle. A Google spreadsheet available on mobile phones was shared between all couples and teams to mark in real-time which apartments were visited, which refused, proved uninhabited or indicated a different timing for a home visit. The aim was not to return to the already visited or refusing apartments and to keep track of progress. To facilitate responding to the structured open questions, one team member engaged in conversation with the inhabitants while the other took detailed notes of the answers on a paper survey with open questions. Recording would be ideal for accuracy; however, a signed consent form would be required to store and process the digital data for research purposes. The consent to record the conversation would also require a consent to process personal information, that is, the name and surname of the interviewee. It was assumed this would deter the interviewees if they were asked to give their names and signatures at the beginning of a fragile contact with the researchers. The researchers introduced themselves and offered the information sheets, the same as those previously distributed. The questions about the main heating system were prioritised and asked first. The rationale for this was to collect primary data first and reduce the inhabitants’ reluctance to participate further in the survey. If the researchers were allowed to enter an apartment, a walk-through interview was conducted based on a standard set of questions, but with an openness to follow new themes related to the research topic, for example, occupancy profiles or household characteristics. Also, the basic living standard (the availability of a bathroom, kitchen, ventilation, visible mould) and technical issues related to the heating system and fuel used, as well as the distribution of heaters were assessed (Baborska-Narozny et al. 2018).

4.3. The most vulnerable households
An additional source of data tested was paper surveys completed by all households in the studied quarter entitled to social care, involving home visits by social workers. Eligibility criteria for such a provision are regulated on a national level and cover the most vulnerable households, in particular those below the official poverty line. Among those households eligible for additional social care, 66% are below the poverty threshold in urban areas (Polish Central Statistical Office 2017) or are those with disability, long-term illness, unemployment or other special needs (Polish Government and Parliament 2004). A survey with open-ended questions was prepared, covering all the themes otherwise explored in this study through mediated conversations. Paper copies of the questionnaire were shared by the researchers with a local social welfare centre. There all the 20 households receiving social support within the target quarter were identified and the surveys were passed to social workers. They distributed and collected the questionnaires over two months during standard home visits. To protect the privacy of the households receiving support, the research team was neither allowed to accompany those visits nor to learn about the visited addresses. The researchers were not informed about the specific reasons underpinning social care over the 20 households. Therefore, these surveys provided reliable data concerning
the living standard of the most vulnerable households and prompted the analysis presented below of fuel poverty. However, as these surveys were unassigned to the specific apartments, they could not supplement the database of the visited apartments, as it was not clear if they were not already visited by the researchers.

5. Findings

The mixed-methods approach proved successful in gathering data: information was collected from 92% of heating systems in the studied apartments (Table 2). Additional detailed feedback was obtained from 50% of all the households approached. The inhabitants who shared their views and allowed the researchers into their homes represented private and social apartments of varied sizes, different occupancy profiles and all the heating systems used in the sample, that is:

- solid fuel: coal and wood, including pellet
- gas
- electricity: both standard and night tariff (‘Economy 7 Tariff’ equivalent)
- district heating.

The distribution of the main heating systems for the whole quarter and for the different tenancies, that is, social and private, is shown in Figure 5. The differences in the distribution for private and social apartments is statistically highly significant (the result of a Fisher’s exact test gives $p = 2.2e^{-16}$, i.e. $p < 0.001$). More than half the social but only one in 10 private apartments are heated through solid-fuel combustion in inefficient stoves, either wood or coal. The prevailing energy source for water heating in solid-fuelled households is electricity: local heaters or boilers, that is, the most expensive water heating method. The more economical heating and water heating options other than solid fuel are least present in social housing. Gas heating is almost fourfold more frequent in private apartments than in social ones and district heating twice as frequent. Electric heating can be found with comparable frequency for both ownership types. However, a closer inspection resulting from the study reveals that the prevailing electric heating in social housing is based on local portable heaters on standard electricity tariffs. Less common are tiled stoves equipped with electric heaters on a night tariff. In private apartments, the portable heaters were not observed, and the prevailing solution is modern storage heaters for the night tariff.

The distribution for the 20 vulnerable households established through responses to the questionnaires is also presented in Figure 5. Statistical significance analysis of the difference in the distribution between all households and the vulnerable households is more complex because those vulnerable are a subset of the whole population. Therefore, in order to ensure that Type I errors do not build up to $>0.05$, an adjustment was made and the Bonferroni correction applied. In its simplest form, it means that instead of using 0.05 as the critical value of significance for each test, the critical value of 0.05 divided by the number of conducted tests (i.e. 2) is used ($0.05/2 = 0.025$). The result of the Fisher’s exact test gives $p = 0.01676$, i.e. $p < 0.025$. Therefore, the difference in the distribution is statistically significant even when applying a stricter and more conservative interpretation of the results.

Among the 20 most vulnerable households surveyed, only one was connected to the district heating. Gas heating was not reported. Four households had electric heating and 15 relied on solid-fuel combustion (Figure 5). In the latter group, either supplementary electrical heating or moisture and mould issues were reported. Four of 20 households were not provided with hot water and used cookers to heat the water. Lack of hot water was not reported in any privately owned apartments.

5.1. Differences in the heating types

Solid-fuel combustion is the cheapest heating option, particularly in cases where households have access to free firewood. However, the present research has revealed inhabitants’ attitudes about solid fuel. The general perception of the inferiority of solid fuel as well as the electric heating on a standard tariff was revealed by the distribution of answers to the question: Would you consider changing the heating system in your apartment to a different one? If yes, what kind of heating would you prefer. The change was regarded as desirable on average by 64% of the inhabitants. Among the households using solid fuel for heating, 84% would welcome change, whereas for apartments with district heating, it was <11% (Figure 6) (Baborska-Narozny et al. 2018). The heating type of preference was either district heating or

![Figure 5: Distribution of different heating sources for different ownership types.](image-url)
gas. Only single inhabitants indicated that solid wood was a preferred choice. The unsatisfied opinions about district heating came from tenements where the change of the heating system was not accompanied by a thermal retrofit.

An analysis of the digitised notes from structured conversations allowed a contextualised assessment to be made of the reasons underpinning the above results. For example, a description of the daily heating practices and perceived thermal comfort in households with adults working full time suggested that the diurnal thermal profile in apartments using biomass combustion in tiled stoves was undesirable: hot through the night and cold in the afternoon. Also, solid fuel transport and storage was raised as an issue, in particular at higher levels and for ageing inhabitants. Some solid-fuelled households praised resilience and autonomy of their heating, that is, independence from power cuts (gas and electric heating would be vulnerable).

Difficulties in obtaining thermal comfort and the moisture problems coincide with the expectation of a change for different heat sources (Figure 6). Walk-through notes indicate that the interior temperatures in solid-fuel heated apartments varied both between dwellings and rooms within a single apartment. The thermal comfort results presented are a robust indication of a general perception of the inhabitants. Further research would be needed to assess quantitatively the severity of the thermal comfort problem.

Another theme of frustration emerged from the walk-through conversations. Many households, mostly social, but also private, were willing but unable to move away from solid-fuel heating. Any effort to improve the very poor technical state of the building would be welcome. One social housing inhabitant wished to ‘live long enough to see proper construction work on this building’.

5.2. Cost of heating

A further analysis was used to estimate the share of heating cost in relation to income. Two income scenarios were considered:

- A household consisting of one working adult with a total net income of PLN1643/month (about £330/month), that is, the minimum wage in 2018.
- A pensioner with a gross income of PLN1065.60/month (about £200/month), that is, the mode (or peak) in the distribution of pensions for women in Poland in 2018.

It is worth noting that a significant gender gap in pensions occurs. The financial value of the most typical individual pension for men (PLN2177.80/month) is twice as much compared with the most typical given to women (PLN1065.60/month). This is because of a gender pay gap and an earlier retirement age for women (ZUS 2018).

These scenarios were identified as likely for social housing based on income thresholds that entitle people to apply for a social apartment. The income scenarios were correlated with the heating cost calculated for:

- three building envelope standards specified by an energy audit commissioned by the municipal FM (this audit was to inform retrofit scenario development for one of the studied buildings)
- two internal temperature scenarios: one meeting building regulations (20°C), the other representing an underheated (16°C) apartment
- heating fuel types identified in the field study.
The first two categories, that is, building thermal standard and internal temperatures, form four tenement types analysed (Table 3):

- Type I: tenement without a thermal retrofit with an internal temperature of 20°C; the usable heating energy demand is 154 kWh/(m² a).
- Type II: tenement after the thermal retrofit of the roof, windows and doors with an internal temperature of 20°C; the usable heating energy demand is 108 kWh/(m² a).
- Type III: tenement after a deep retrofit with an internal temperature of 20°C; the usable heating energy demand is 59 kWh/(m² a).
- Type IV: tenement without a thermal retrofit with an internal temperature of 16°C; the usable heating energy demand is 104 kWh/(m² a).

The external temperatures data for Wroclaw are derived from the Meteonorm database for the period 2012–17. Recent years in Wroclaw were much warmer than those described by the typical meteorological year based on a 30-year average (Figure 7).

Table 4 shows the average heating costs in PLN/m² per month, spread evenly across the year, for each fuel and building type analysed. The costs are based on average market unit prices of the energy carriers and heating systems’ efficiency assumed for energy performance certificates calculations. The energy prices differ depending on location, carrier provider or economic situation. The assumed system efficiencies may not represent the reality, for example, because of maintenance issues. Sensitivity analysis of the heating costs on the change of systems’ efficiency and the change of the unit price of the energy carriers is shown (Figure 8). The results are presented for pre-retrofit and deep retrofit scenarios (Types I and III). The change of efficiency (the darker shade in Figure 8) of ±10% has a greater influence on the heating costs in pre-retrofit buildings than those after deep retrofit. The fluctuation of energy carrier prices (the lighter shade in Figure 8) is most prominent for coal-heated systems as the quality (coal sludge to coke) and prices of coal are in the range of PLN500–1210/tonne. The resulting heating costs might be in a range of PLN1.60–3.89/m² per month in pre-retrofit tenements; however, coke is not a fuel used in old stoves. For further analysis the mean costs are used.

Table 3: Characteristics of the four modelled scenarios.

| Tenement house type | Internal temperature (°C) | Heat transfer coefficient (W/m²K) | Heating energy demand (kWh/m² a)* |
|---------------------|---------------------------|----------------------------------|----------------------------------|
|                     |                           | Walls | Roof | Windows | Doors |                  |
| I                   | 20                        | 0.87  | 0.84 | 2.14    | 5.10  | 154               |
| II                  | 20                        | 0.87  | 0.18 | 1.10    | 1.50  | 108               |
| III                 | 20                        | 0.23  | 0.18 | 1.10    | 1.50  | 59                |
| IV                  | 16                        | 0.87  | 0.84 | 2.14    | 5.10  | 104               |

Notes: Types I–III = gradual improvement of thermal efficiency of the envelope; and IV = lower internal temperature and low envelope efficiency.

*Estimates are based on a detailed energy audit of one tenement in the quarter.

Table 4: Approximate heating costs in tenements for the adopted thermal envelope standards and heating profiles (PLN/m² per month) depending on the fuel type in the temperatures of a typical meteorological year.

| Type | Energy audit proxy of heating costs (PLN/m² per month)* |
|------|---------------------------------------------------------|
|      | District heating | Electricity standard tariff | Electricity night tariff | Gas | Coal, tiled stove |
| I    | 3.0             | 7.4                       | 3.8                      | 3.2 | 2.5               |
| II   | 2.1             | 5.2                       | 2.7                      | 2.3 | 1.8               |
| III  | 1.2             | 2.9                       | 1.5                      | 1.3 | 1.0               |
| IV   | 2.1             | 5.0                       | 2.6                      | 2.2 | 1.7               |

Note: *Energy prices are based on the current tariffs of key utility providers in Wroclaw and on an average market price of standard quality coal.
Solid-fuel-based systems generate the lowest heating costs. Assuming that a temperature of 20°C was maintained, heating costs would be around PLN2.5/m² per month in Type I apartments. Three alternatives to solid-fuel combustion are typically considered in Poland, that is, district heating, natural gas or electricity. The first two options induce a similar cost increase to about PLN3.0 and 3.1/m² per month, respectively. Opting for electric heating means cost increase to PLN3.8 or 7.4/m² per month depending on the electricity tariff, that is, night or standard. Installing electric heating is easier to implement and cheaper than gas at the investment stage. This proves popular among social housing inhabitants desperate to get rid of the burdens related to using solid fuel. The high costs might be 2.5 times lower following a deep retrofit (Type III). As revealed by this study, electric heating is not only more common in social housing than gas or district heating but also is a source of additional heating used by the majority of solid-fuel households wishing to improve their thermal comfort in unheated spaces (Baborska-Narozny et al. 2018). As mentioned above, this unfavourable situation affects the poorest sectors of society and often leads to underheating represented by Type IV apartments. In the lowest income households, cost-cutting may result in using cheaper, more polluting coal substitutes or burning waste. Such occurrences, though rare, were observed during the site visits.

The costs identified were applied to all 300 social apartments in the studied population, based on their sizes and current heating system (Figures 9 and 10, 'heating structure' column). The resulting heating costs for each apartment were compared with an expenditure-based fuel poverty metric of 10% of annual income (Rademaekers et al. 2016). Typically, the expenditure-based fuel poverty includes spending on all the 'required' energy services, thus, for example, hot water cost is included. Here the 10% threshold is applied to the cost of heating only to eliminate the error-prone assumptions about the household's water consumption level (Gill et al. 2010) or the cost of water heating as different fuels (electricity, gas), appliances (storage or tankless water heaters, cookers) or bathroom facilities scenarios were observed during home visits. Further context sensitive research is needed to generate a reliable description of the water consumption costs. Their exclusion means the scale of fuel poverty is generally underestimated.

The number of households vulnerable to fuel poverty for an income scenario of a minimum monthly wage is shown in Figure 9; and for an income equal to the most typical pension for women in Figure 10.
The results in Figure 9 indicate that for a standard tariff electric heating in the pre-retrofit situation (Type I), the fuel poverty would affect even the households living in apartments with floor area <35 m². All other heating systems achieve a temperature of 20°C for apartments <79 m². For the biggest apartments of >79 m² in the pre-retrofit scenario, only solid-fuel combustion allows most households to stay out of fuel poverty. All other heating systems, except for electric heating, require a thermal retrofit to achieve that effect. Electric heating on a standard tariff should only be considered for the deep retrofit scenario (Type III) in apartments <79 m². Otherwise, it is linked to fuel poverty.

Figure 9: Number of fuel-poor households with a minimum income for varied retrofit scenarios and internal temperatures (Types I–IV) related to the actual structure of social apartments’ sizes and heating systems in the studied quarter.

Figure 10: Number of fuel-poor households with a retired woman on mode pension for varied retrofit scenarios and internal temperatures (Types I–IV) related to the actual structure of social apartments’ sizes and heating systems in the studied quarter.
A household with an income level of the most typical pension for a woman would be vulnerable to fuel poverty regardless of the heating system for the Type I, II and IV scenarios for apartments >79 m². The only exception would be a deep retrofit and avoiding electric heating. Standard tariff electric heating should be avoided for all apartment sizes, except for the smallest ones after a deep retrofit. Keeping that in mind for the apartment with a floor area of 56.1–79 m², only a deep retrofit avoids fuel poverty. For the prevailing size of an apartment of 35.1–56 m², even solid fuel cannot guarantee the avoidance of fuel poverty in the pre-retrofit situation. However, keeping the apartment underheated (Type IV) does protect from expenditure-based fuel poverty, but at substandard living conditions.

6. Discussion
The distribution of the heating systems observed in the studied quarter indicated the disadvantaged position of social housing residents, and even higher levels of fuel poverty for the most vulnerable households. Solid fuel or expensive electric heating, neither covering all habitable spaces, prevail.

The modelling results confirm inhabitants’ feedback on their preferred heating options.

The results also shed a light on the gender aspect of fuel poverty. In Poland, women on average live longer by 7.9 years than men, but they retire at the younger age of 60, that is, five years earlier than men. The gender pay gap is also a common phenomenon in Poland. The cumulative impact on retirement is substantial: the most typical pension for men is more than double that for women (ZUS 2018). The most typical man’s pension is greater than the minimum monthly wage (scenario 1) used in this analysis. If a solid fuel ban is introduced, the findings indicate a new vulnerability is created for tenement households living on a woman’s pension. The increased energy costs would result in fuel poverty. That vulnerability would be decreased if the change of energy source were accompanied by a deep thermal retrofit of the building envelope.

A deep retrofit is typically linked to increased air tightness. A standard ventilation strategy for tenements both before and post-retrofit is natural ventilation, with new trickle vents in air-tight windows. Whether this low-cost solution leads to poor indoor air quality and moisture issues (May & Sanders 2017) needs to be evaluated specifically for the Polish context. Consideration also needs to be given to natural ventilation in summer to avoid excess overheating, especially for neighbourhoods that may be noisy or unsafe. At present, the tenements are exempt from building regulations regarding ventilation strategies, for example, minimum values of air changes per hour or separate ventilation shafts for each apartment. In addition, there are no binding targets for air quality inside listed residential buildings. Further research is needed to understand the internal air quality in tenement apartments post-retrofit.

No options other than gas, electric or district heating are currently considered in Wrocław for central urban tenement locations. Renewables are considered a last resort, attractive only if there no gas or district heating in the area. Context-based research is needed urgently to explore alternative solutions, as most changes must be implemented before 1 July 2024, a deadline imposed by the local air-quality resolution. Within that time the change will affect nearly 20,000 households across the city (zimnocieplo.pwr.edu.pl).

The short timescale for major changes is an important issue. The air-quality EU-level policies are more than a decade old. The current rushed local response to them, for example, the ‘Change the Stove’ policy in Wrocław, introduced without the coherent support of national policies, focus on numerical targets, that is, the numbers of solid fuel furnaces or stoves that need to be deactivated to improve air quality. The alternatives, though less polluting, are still fossil fuel based. This represents a missed policy opportunity to address broader climate change issues by significantly decarbonising the domestic building stock and reducing energy demand. While district heating is perceived in some countries as a fairly sustainable option (Lake, Rezaie, & Beyerlein 2017), in Polish cities the problem is the outdated infrastructure. The financial and organisational effort to implement the transition away from solid-fuel combustion will be huge. A better use of resources would be to create a basket of measures for both housing retrofit and energy systems. The EU is about to withdraw its investment in gas, so it is ironic that Poland intends to increase its dependence on that fuel.

Denmark’s shift away from fossil fuels started in 1976 and is still ongoing (Hvelplund 2013). Germany’s environmental policy also started around this time. The topic of the environment was constantly present in the political discourse because of the Green Party as well as public pressure (Ehnert 2019). The German government agreed to the concept of ecological modernisation in 1980. In Poland and other CEE countries, the policy shift is just beginning (Bouzarovski et al. 2016; Buzar, 2007; Herrero & Urge-Vorsatz 2012), thus its speed must be unprecedented or the region will increasingly disconnect from EU policies and practices. Major research efforts are urgently needed at this crucial stage to inform the policy at all levels about the justice implications of the different decarbonisation scenarios.

Wrocław’s air-quality-focused policies triggered the process of improving tenements through retrofits. However, this only applies to the 100% municipality owned buildings, that is, nine out of 27 in the studied quarter. The majority of the inhabitants using solid fuels, regardless of the building ownership structure, welcome the change. Current policy is inconsistent and unjust as the social housing tenants will be subject to different transition strategies depending on an ownership structure of a building they inhabit. These strategies differ in terms of creating fuel poverty. The majority living in the mixed-tenure tenements will be incentivised to choose the most disadvantageous alternative, that is, of electric heating without building retrofit.

Limitations apply to the presented findings, which are based on the deprived area of the city and focus on a homogenous building typology of heritage tenements with a particularly high mix of social housing. The findings are
not representative of the residential sector in the whole city. A follow-up study to address this gap was commissioned by the municipality in order to estimate the scale of the solid-fuel combustion challenge for all housing typologies in the city. Second, the inhabitants’ feedback relating to indoor thermal, moisture or air-movement conditions was not correlated with monitoring data. A walk-through method was instrumental for observing patterns in issues raised by the inhabitants. Only some issues are possible to confirm on a spot-check visit, for example, visible mould. Other issues need to be further examined with monitoring. Therefore, an in-depth socio-technical research project on a sample of households with different heating systems and thermal envelope standards is about to begin. Clear data on energy consumption and temperature monitoring combined with inhabitant practices are necessary to create a validated model. The model will provide better understanding of the impact of different scenarios (retrofit and different energy sources for space heating) on the change of heating cost.

The calculation of the cost of heating presented in this study does not aspire to represent reality fully and should be understood as an illustration of a trend. It involves a simplified assumption about the linear increase of the heating cost with the increase in the floor area of an apartment. The reality is more complex as, for example, the proportion of external walls to floor area for different dwelling sizes is not constant. The heating demand level used for the different retrofit scenarios is based on a detailed energy audit of a tenement within the studied quarter. However, it does not reveal the impact of different apartment orientations, inhabitant heating practices or the rebound effect. For example, it does not account for the cost of additional heating identified as characteristic for solid-fuel households. The fuel poverty threshold of 10% of one’s annual income spent on energy bills is based on British fuel poverty indicators. Nowadays, the official method for the UK is the low-income high-cost indicator (LIHC). The authors used the 10% indicator for its simplicity, not to introduce further variables into the calculations. There is research suggesting the fuel poverty threshold should be tailored to the local context (Castaño-Rosa et al. 2019). Despite these limitations, the cost simulation is based on the accurate structure of social apartment sizes and the main heating systems in place identified in this study, current income levels, climatic conditions and fuel prices. Therefore, it is illustrative for the scope of fuel poverty challenge to be expected for different scenarios.

7. Conclusions

The real-world study covering 422 apartments in listed tenements in a major Polish city revealed an increased vulnerability to fuel poverty. This new vulnerability arises from policies with the aim to improve air quality and reduce CO₂ emissions by banning solid-fuel combustion for heating purposes. However, care must be taken to avoid climate injustice as an unintended consequence. Context is an essential consideration and the design of policy measures must account for variations in the built environment as well as the socioeconomic of its inhabitants. This study has shown that fossil fuel heating in tenements is concentrated in the most technically deprived, energy-inefficient building stock and it affects the least affluent part of society, already vulnerable to fuel poverty. This vulnerability increases with the floor area of an apartment and is gender related because of a gender pay gap, which is particularly acute for pensioners.

The cost of heating using different energy sources and fuels varies, but is generally the lowest for solid fuels. Therefore, the necessary transition away from solid fuels is likely to result in increased heating costs. The severity of the increase depends on the selected alternative. SAP equivalent modelling suggests the operational cost of gas or district heating is about 20–25% more expensive than coal. However, electric heating on a standard tariff is about three times more expensive than coal. A paradox exists for tenants: the choice between (1) heating systems with low installation costs (CAPEX) and high energy costs (OPEX) versus (2) one with a higher CAPEX and low OPEX. In the studied population, over 80% of users of cheap CAPEX and expensive OPEX systems wanted to change it for one with low operational costs. They also reported underheating. Underheating is generally linked to moisture-related problems leading to adverse health effects. The survey of housing revealed that the costly electric heating is most common alternative to solid fuels in social housing, whereas in privately owned apartments, the cheaper-to-operate heating options prevail. This distribution suggests that without deep thermal retrofit of the listed buildings, fuel poverty and underheating will be difficult to avoid. Currently, two different policies are implemented in Wrocław to accelerate the process of transition away from solid fuel. One will result in thermally retrofit tenement buildings connected to district heating, a preferred option according to our findings. The other will result in an increase in uninsulated apartments heated with electricity, that is, the least advantageous scenario.

Policy implications for the avoidance of injustice are the following:

- It is vital for air-quality policies to protect the poorest people and not increase their vulnerabilities. This means maintaining low operational costs when transitioning to new fuels for space heating. Combining a change of heating system with additional support (thermal retrofit and appropriate pricing of alternative fuels) is the only realistic option for social housing interventions and the first choice for other tenure types. Otherwise, the poorest inhabitants can no longer afford to heat their homes because of a ban on solid fuels.
- Air quality-driven polices focused on solid-fuel eradication should not ignore fuel poverty already experienced mainly by social housing residents using electric heating on a standard tariff. This group should be supported in changing their heating system together with the solid-fuel households.
- The rebound effect is likely to be significant after thermal retrofit and change of heating. Currently, most apartments designated for change are perceived as cold. An increase in thermal comfort means that energy savings
might be lower than expected. Any rise of rent linked to the improved apartment standard would not be compensated for by savings on heating.

- Gentrification risk related to the likely improvement of living standards is a complex issue. Avoiding contrasts of living standards across the social housing stock might reduce the displacement of the most vulnerable inhabitants to the worse apartments.

- Air quality local regulations respond to an urgent agenda for reducing GHG emissions and improving air quality as a public health priority. However, a more ambitious national approach to solid-fuel eradication would enable access to EU funding. Poland’s proposed heating alternatives still rely on fossil fuels (gas and coal in CHP plants), that is, options not supported by the EU.

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