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REVIEW ARTICLE

Energy efficiency of buildings in Central and Eastern Europe: room for improvement

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Abstract Following the invasion of Ukraine and the associated energy policy tensions with Russia, the EU began looking at how it could replace Russian energy sources. One of the proposed solutions is to decrease energy consumption. Buildings have been the principal target, owing to their high energy usage – especially of natural gas, which the EU is particularly keen on reducing. This literature review article summarises existing knowledge on the potential energy savings that can be made through energy efficiency improvements to existing buildings in Central and Eastern Europe. The countries in this region share common traits due to their Communist past and associated legacy of poor energy efficiency, both generally and in buildings in particular. At the same time, Central and Eastern Europe contains a range of geographical and climatic regions, and so, the findings of this paper are applicable to other regions. This bibliometric analysis identifies three main areas (insulation, heating source and policy) in which the academic literature has identified potential for energy efficiency improvements to buildings. On the basis of these findings, this paper looks at the policy implications for reducing energy consumption in buildings and thus helps the EU to become less dependent on energy supplies from Russia.

Keywords Central and Eastern Europe · Energy efficiency · Refurbishment · Renewables · Insulation · Policy

Introduction

The European Union aims to significantly reduce its carbon footprint to achieve carbon neutrality by 2050 (European Council, 2019). In order to achieve this goal, the EU has adopted two sets of partial targets for 2020 and 2030 (Proedrou, 2020). These include greater use of renewable energy sources, reducing greenhouse gas (GHG) emissions and improving energy efficiency. While the latter relates to multiple economic sectors, including industry and transport, a significant proportion of the energy efficiency efforts are targeted at buildings, making them an important part of EU energy policy (Zangheri et al., 2018). Buildings are responsible for approximately 36% of energy consumption in the EU (del Solà et al., 2020) and 36% of CO_2 emissions (European Commission, 2021). The EU has been developing energy efficiency policies for buildings since the 1970s; however, the main impetus came in 2002 with the first Energy Performance of Buildings Directive (2002/91/EC) (Economidou et al., 2020). The directive has

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facilitated the process of cost-effective retrofitting of existing buildings to meet the nearly zero-energy building standards. However, this is a mammoth task as approximately 75% of buildings in the EU are energy inefficient, and the renovation rate is very low (and varies between member states, with 0.4 to 1.2% of overall building stock (i.e. private and public) being renovated each year) (European Commission, 2020).

In order to speed up the renovating pace, the directive has repeatedly been amended, and the most recent 2018 version (Directive (EU) 2018/844) is currently being revised (COM (2021) 802 final). Already the 2010 amendment (2010/31/EU) of the 2002 Directive was aimed at achieving near zero-energy building standards in all new public buildings from 2019 and new private ones from 2021 (Attia et al., 2017). Under the 2012 revision of the directive (Directive 2012/27/EU), member states must renovate at least 3% of the total floor area of buildings utilised by central governments annually (Felius et al., 2020). There is huge potential in renovating old energy-inefficient building stock (Kivimaa & Martiskainen, 2018); the post-pandemic recovery mechanism, therefore, encourages the use of EU funds to improve energy efficiency in buildings and thereby reduce the Union's carbon footprint (European Commission, 2023).

Following the February 2022 invasion of Ukraine by Russia and the energy challenges faced by the EU (Mišík, 2022), the European Commission presented a plan for reducing EU dependency on Russian energy sources – particularly natural gas – in both the long (European Commission, 2022a) and short term (European Commission, 2022b). Natural gas is an important heating source in many EU member countries, and shortages would present a risk to households as well as other customers. Hence, energy-efficient buildings will play a crucial role, and efficiency improvements will help the EU to reduce the amount of (Russian) gas in the energy mix. Indeed, the EU (European Commission, 2022b) and the International Energy Agency (International Energy Agency, 2022) have set out recommendations on how end customers can reduce energy consumed (and thereby energy bills) through heating and other household-related activities.

The central aim of this paper is to examine what the existing literature can tell us about the potential for reducing energy consumption in buildings by increasing their energy efficiency. We focus on Central and Eastern Europe (CEE) as this region performs poorly in energy efficiency generally (Mišík & Oravcová, 2021) and in buildings in particular (Cirman et al., 2013). A huge portion of the housing stock in CEE was built during the Communist era. At the same time, however, there are climate differences between the northern and southern parts and between the mountains and flat areas in this region (Csoknyai et al., 2016). Therefore, while some of the findings in this review will be region-specific, others will be applicable to other regions of the EU as well (and probably even more widely). We examine the period between 2004 (when most of the CEE countries joined the EU) and 2019 when the European Green Deal was adopted. We have identified 514 academic papers investigating issues connected to buildings in the CEE region in this period.

The following section introduces the methodological underpinning of the research, and the third section presents an overview of our findings. In the fourth section, we look at three issues where there is scope to reduce building energy consumption in CEE: insulation, replacement of heating sources and central heating refurbishment, and changes to building policy. The fifth section discusses the main findings of the papers, while the last one presents conclusions, looks at the policy implications and identifies the limits of this analysis.

Methodology

We used the Web of Science core collection database (WoS) to create our dataset and collected articles published between 2004 and 2019, from the beginning of the EU's Eastern enlargement to the introduction of the European Green Deal (EGD) which can still be considered the EU's main climate and energy policy initiative for achieving the EU's 2050 decarbonisation goal. While this period does not cover the current energy crisis which has significantly changed the EU's views on energy efficiency and energy security (European Commission, 2022a), it does cover the 2006 and 2009 gas crises which impacted especially the CEE region (Mišík & Nosko, 2023). The end date of the studied period connected to the EGD was chosen to learn about the starting position of the CEE region when it comes to decarbonisation efforts in the building sector needed to support 2050 as the year when the EU's economy should – according to the EGD – be decarbonised. First, we decided to aim for a broad selection of articles and selected all articles on energy research in CEE. Second, we narrowed this down to articles on buildings. Finally, we identified three main topics, and these are examined in detail in the fourth section of this paper.

We selected the CEE region for several reasons. The countries in this region are similar in several respects, the most important of which is the shared Communist legacy that has left a visible footprint on the building stock. The rapid urbanisation in CEE countries led to a housing boom and the construction of prefabricated buildings typical to the region, especially during the 1970s and 1980s (Kährik & Tammaru, 2010; Stanilov, 2007; Wiest, 2011). These and other types of residential buildings characteristically have low energy efficiency as energy was in abundance when these buildings were built (Högselius, 2012). After the fall of Communism and the increase in energy prices, some households began to experience energy poverty, but very little was done to improve the energy efficiency of the buildings (Chelcea & Druţă, 2016). Energy poverty thus remained a problem within the region (Bouzarovski & Tirado Herrero, 2017). However, these challenges represent great potential for energy savings in CEE, which will, in turn, help the EU to wean itself off its dependence on Russian energy sources, especially natural gas, which is the main heating fuel in many countries of the region.

Despite these similarities, CEE countries vary in building type and energy consumption. The region includes the colder Baltic states as well as the Balkan countries with their Mediterranean climates. Moreover, some countries are mountainous, while others are largely flat; some are land-locked, and others are coastal. There are other differences between CEE countries too, limiting our ability to make generalisable conclusions for the whole region, but that also makes our findings transferable to other parts of the EU and the world.

In the first step, we created our main database using WoS and obtained all articles (in English) with a combination of the following two keywords in the title, abstract or keywords. The first keyword was 'energy', and the second one referred to the CEE country by name ('Romania, 'Hungary', etc.) or adjective ('Romanian', 'Hungarian', etc.) or in regional or subregional terms ('Baltic', 'Baltics', 'Central Europe', 'Visegrad', 'CEE', 'CEEC', 'V4'). We excluded articles that did not refer to any of the 11 CEE countries – for example, some articles on Central Europe analysed Austria or Germany. We also excluded articles that were about other types of energy (e.g. energy in the biological sense) and those in which 'polish' did not refer to Poland. We selected research articles only and excluded books, book chapters, book reviews and conference papers. After excluding these, our main database contained 3534 articles.

In the second step, we selected articles that examined energy issues in buildings, creating a 'building' database containing 514 articles. This database contains information on the articles (authors, title, journal, year) and the content – academic discipline (science, economics, social science, (natural) science, interdisciplinary), type of energy (energy in general, oil, natural gas, coal, biogas, geothermal etc.) and area of the EU's energy and climate policy under the Energy Union division (decarbonisation, energy efficiency, internal energy market, energy security, research and innovation). In the third step, we coded the articles according to the topic covered, focusing on how changes to existing buildings connected to energy efficiency can reduce energy consumption. Our research was concerned with changes in the thermal (and other) properties of buildings that generate energy savings, so we excluded articles on the 'static' properties of buildings (like the measurement values of nearly zero-energy buildings, energy storage etc.) as they tell us little about modifying the existing building stock to reduce energy consumption. We, therefore, focused on articles that examine existing buildings and how their improvements can lead to an increase in energy efficiency – this is the main building policy challenge of the CEE region. Consequently, we did not cover literature on new(er) buildings that benefit from a stricter regulatory environment brought by the EU (see Introduction). Our final dataset contained 280 articles (see Fig. 1).

We identified three main topics in the existing literature relating to potential improvements to existing buildings to reduce energy consumption: insulation, heating source and policy. Here, 'Insulation' refers to improvements to building envelopes (including walls, windows etc.), which can improve the building's

Fig. 1 Creation of dataset. Source: Authors

energy efficiency. 'Heating source' relates to the generation of heat in buildings and how, for example, replacing or retrofitting old sources can improve building energy efficiency. 'Policy' refers to various ways in which the energy efficiency of buildings can be improved on the policy level (including but not limited to change of behaviour).

Description of the data

Following the methodology discussed in the previous section, we first looked at the dataset from a broad perspective. Of the 3534 articles published between 2004 and 2019 on energy in Central and Eastern Europe, 514 examined various building-related issues. That means that 14.5% of all the articles on energy in the region looked at buildings, which is not much given how much they contribute to the overall energy consumption (approximately 36%) and emissions (36% of CO_2 – see 'Introduction'). Buildings consequently receive a lot of attention from policy-makers, but that does not appear to be mirrored in the literature – at least not in Central and Eastern Europe. Figure 2 shows the share of articles on the three main topics identified in this paper that contribute to reducing building energy consumption: insulating building envelopes (91 articles), heating source improvements (88) and building energy policy (101). A significant proportion of articles on energy and buildings (234 or 45.5%) did not relate to these three main topics (see 'Methodology'). We, therefore, excluded them from the rest of the analysis.

We also looked at how interest in buildings and energy in Central and Eastern Europe has changed over time. The two lines in Fig. 3 show the increase in academic interest in energy generally in the region (blue) and in relation to buildings (orange) specifically. Interest in buildings has risen much less gradually than interest in energy generally. Although interest in different aspects of energy consumption in buildings did grow initially, it tailed off, especially after 2014. In that year, 60 articles (i.e. including those not on the three main topics) were published, rising to only 89 in 2019 (less than a 50% increase). This increase is much smaller than the rise in interest in energy generally in Central and Eastern Europe, which grew from 276 articles in 2014 to 554 in 2019 (just over 100%).

Publications on the three main topics identified in this paper increased throughout most of the period, although at the beginning of the period, there were two years when no articles were published on these topics (2005 and 2009). However, it is difficult to draw any conclusions from this, given the low number of articles.

In Fig. 4, we present the number of articles on CEE countries. Poland was most often the subject of analysis, but this is not surprising given the size of the country and its academia. What is more interesting is that Lithuania comes second and Latvia third – these are much smaller countries with much smaller academia. The data do not show any significant

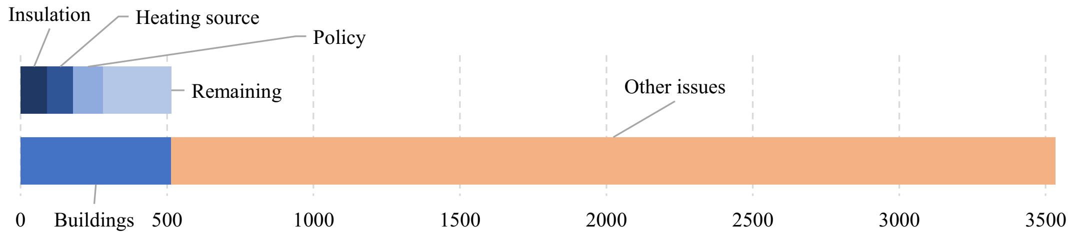

Fig. 2 Share of articles on buildings in the overall dataset and the three identified areas ($N = 3534$). Source: authors

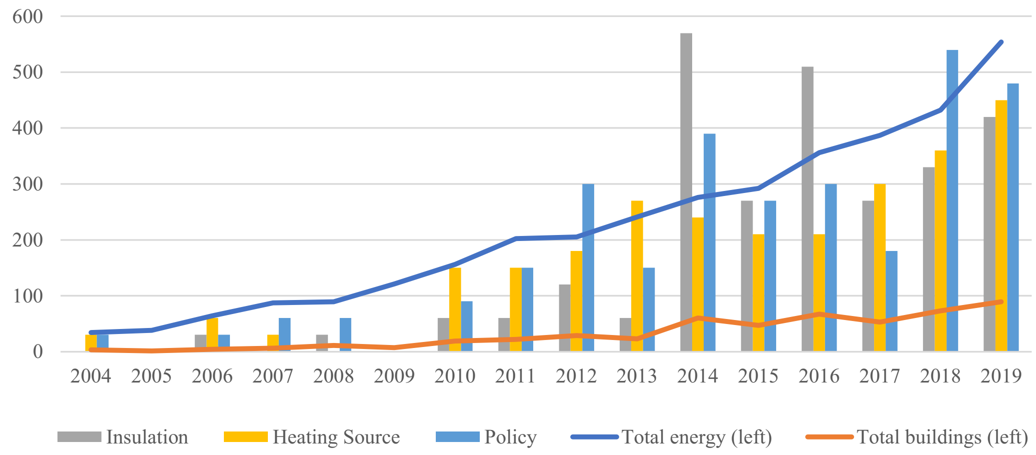

Fig. 3 Articles published on energy in CEE over the examined period. Note: $N = 3534$; data referring to the right axis if not indicated otherwise. Source: authors

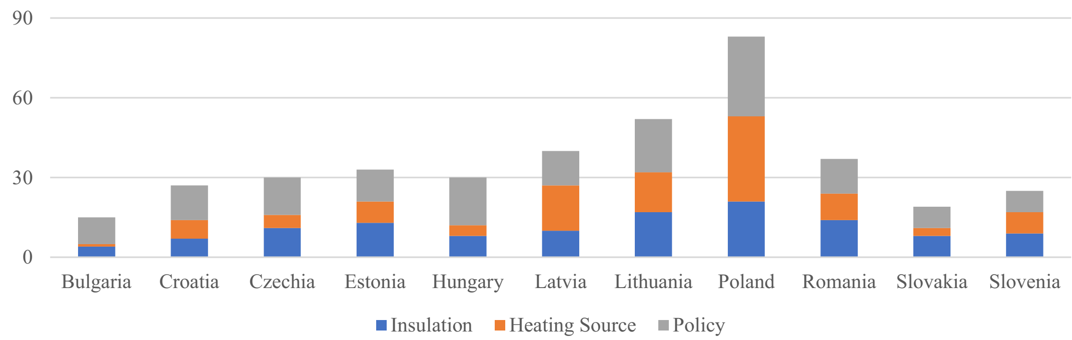

Fig. 4 Countries examined in articles on the three topics. Note: $N = 391$; articles feature in several categories if they cover multiple countries. Source: authors

between-country differences in the topics discussed, apart from Bulgaria which was the subject of several articles on energy poverty (included under energy policy).

The majority of the articles discussed buildings independently of energy source (i.e. 'General' category in Fig. 5). This was especially true of articles on different ways of improving energy efficiency using insulation. Articles on building policy tended not to differentiate between energy sources, although solar energy as an examined energy source for buildings featured most often in this set of articles. Although we merged solar thermal and solar photovoltaic into 'Solar' during general discussions, we are making a distinction between these two energy sources when examining particular issues (see, for example, 'Heating Source'). By contrast, articles discussing heating sources tended to frame their investigations within a specific type of energy source, although solar energy – the most frequent source – was covered in fewer articles than energy generally. Biomass and renewables were mentioned fairly frequently as sources in refurbished (or replaced) heating systems.

Figure 6 below shows the main academic disciplines of the articles on energy in buildings in CEE. The majority came under (natural) science and looked at changes in the energy proprieties of refurbished buildings. Interdisciplinary articles incorporating at least two main disciplines represented a substantial proportion, while the smallest share of articles was from an economic perspective and examined financial and related issues regarding

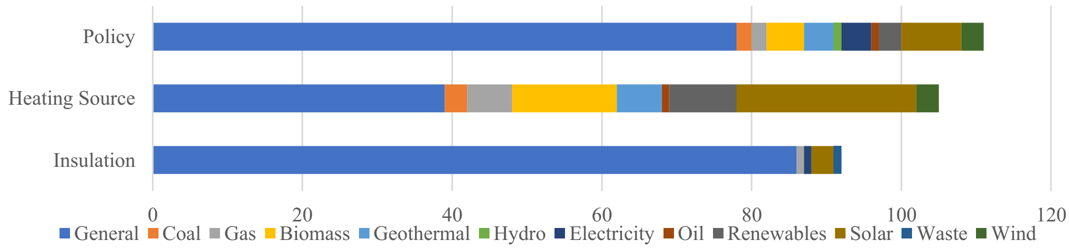

Fig. 5 Energy sources discussed in articles. Note: N = 308; articles are featured several times in the same category if they cover multiple energy sources (e.g. discuss gas and biomass in heating); air source heat pumps are included under 'general', while ground source heat pumps are included under 'geothermal'; we merged solar thermal and solar photovoltaics into 'Solar'. Source: authors

energy utilisation in buildings. Social science is represented more often, particularly in relation to building policy.

Altogether, our dataset contained articles on energy in Central and Eastern Europe published in 159 academic journals indexed in the WoS database. Figure 7 presents information about the 10 most frequent journals containing articles on the three main topics. *Energy and Buildings* is the clear leader, unsurprisingly, given the journal's focus on buildings and energy issues. Almost one-third of all the articles on this topic were published in this journal. *Energy* comes second and *Energy Policy* third. Given the large number of journals publishing research on buildings in CEE, one can argue that apart from *Energy and Buildings*, the research is scattered. One of the contributions of the present paper is that it brings together information that is spread thinly across more than 150 journals containing one article – or a couple of articles – each.

Three ways of improving buildings energy efficiency in Central and Eastern Europe

In this section, we examine the three main topics identified in the existing literature in relation to energy efficiency improvements in buildings in Central and Eastern Europe. Our focus is on the main lessons identified in these articles for improving the energy efficiency of the building stock by insulating parts of the building envelope, replacing or refurbishing existing heating sources, and modifications to building policies.

Insulation

Building insulation has huge potential for reducing energy consumption. It has been estimated that insulating residential buildings alone could bring annual energy savings of up to 90 Mtoe in the EU, although it would require extremely high refurbishment rates and investments of up to 0.15% of GDP annually (Lechtenböhmer & Schüring, 2011). The proportion of insulated old buildings in the CEE region is small, mainly due to the high cost: Czechia is an exception thanks to its public retrofitting programmes (Csoknyai et al., 2016). The existing literature on the CEE region focuses on two types of insulation in old buildings: external walls and windows.

Thermal insulation of external walls has a very positive impact on energy efficiency. Looking at the economic side (energy bill savings) and the environmental (fall in GHG emissions) side in Poland, Dylewski and Adamczyk argue that 'the best results are obtained by thermal insulation made of polystyrene foam or ecofibre' (Dylewski & Adamczyk, 2011, p. 2622). In single-generation homes, the latter was found to be the most ecologically cost-effective option (Dylewski & Adamczyk, 2016a). Environmental benefits of insulation have the potential to outweigh the benefits of reduced energy consumption that are, however, still significant: Mitterpach et al. (2016) argued that, in the case of Slovakia, these can amount to 39% of thermal energy spent. Indeed, the economic benefits of insulating old buildings are far from marginal; another research claimed that comprehensive building retrofitting can reduce energy costs by 40% (Sojkova et al., 2019). After renovation, actual (i.e. not estimated) energy use in a Polish

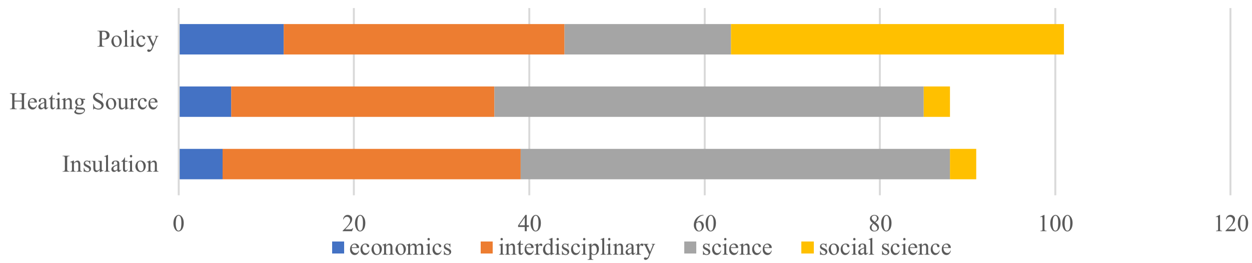

Fig. 6 Distribution of articles by main discipline. Note: $N = 280$. Source: authors

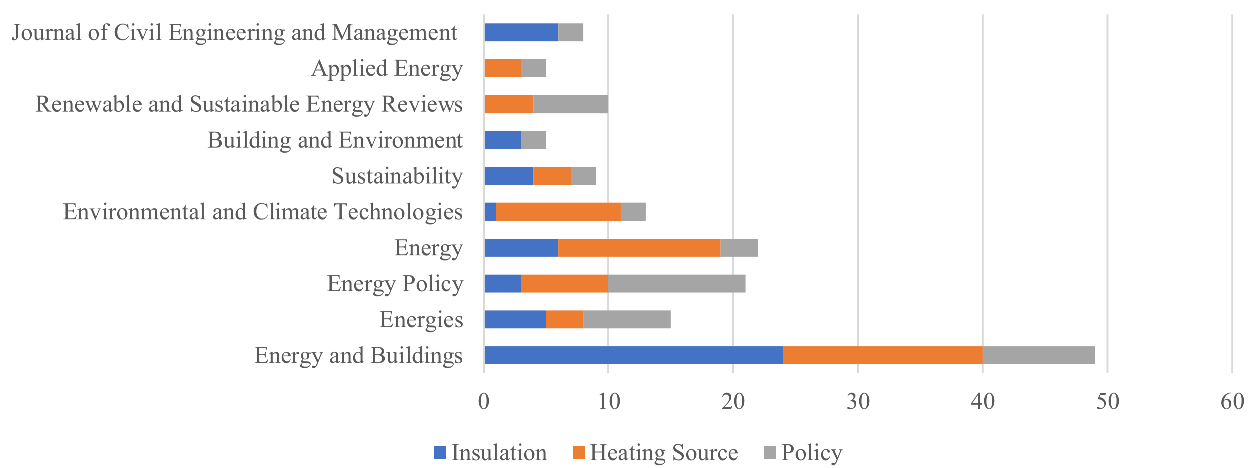

Fig. 7 Distribution of articles across academic journals (10 most frequent journals). Note: $N = 243$; *Journal of Civil Engineering and Management* is based in Lithuania, *Environmental and Climate Technologies* in Latvia, and the rest are published by Elsevier and MDPI. Source: authors

public school decreased by 33% (Krawczyk, 2014). Positive effects are present independently of technology: Renovation brings some environmental benefits even when the least effective refurbishment model is selected (Dylewski & Adamczyk, 2016b). However, the most cost-effective benefits are obtained when the best available technology is used. Examining the Lithuanian case in 2014, it was claimed that upgrading apartments was most effective when the requirements of the 2010 version of the Energy Performance of Buildings Directive were followed, rather than the lower (and cheaper) domestic energy efficiency standards (Ruzgys et al., 2014). Research conducted in Lithuania found that energy consumption of heating fell on average by 49% after retrofitting (Du et al., 2019).

Wall insulation saves much more energy than heating source replacement, although the best solution is to insulate the walls and replace the heating source as well (Dovjak et al., 2010). Similar results were also obtained from an analysis of brick apartment buildings in Estonia, claiming that the highest energy savings can be achieved through wall insulation (Kuusk et al., 2014). Insulating the walls can bring the energy efficiency of old brick buildings up to the level of new builds. However, existing research identified high costs as a primary obstacle to wall insulation for homeowners. Therefore, owners should be motivated to insulate their homes through financial stimuli (Kurnitski et al., 2014). Policies aimed at improving energy efficiency through the provision of subsidies for insulation should focus on apartment buildings because these can be refurbished in line with the energy efficiency standards for new buildings (Kuusk & Kalamees, 2016).

The decrease in air quality caused by insulation has also been the subject of several studies of the CEE region. Research in Romania found that insulation using expanded polystyrene brought energy savings of 55% and was more suitable than extruded polystyrene or rigid polyurethane as it 'allows the water steam gathered in the rooms (mostly during winter) to exit, reducing the condensing risk of the steam' (Nicolae & George-Vlad, 2015, p. 84). Similarly, looking at apartment building renovations in Slovakia, Földváry et al. (2017) claimed that they came at the price of poorer indoor air quality. Therefore, they recommend taking ventilation into consideration when refurbishing this type of building. Other studies have confirmed that air quality decreased (and particle matter increased) following insulation and its connected improvements to the airtightness of buildings (Gens et al., 2014). However, examining three Romanian schools, Ghita and Catalina (2015) argued that the higher energy consumption associated with not insulating does not improve air quality more than building renovations do. Residents in Lithuania (and Finland) reported refurbishment had positive effects overall (Haverinen-Shaughnessy et al., 2018), although a higher CO_2 concentration and lower air exchange rates were observed as well (Leivo et al., 2017).

Another challenge is connected to the age of the buildings. It has been argued that the era in which the buildings were built is an important factor. Very old buildings 'require substantial reconstruction aside from the improvement of thermal properties, making the feasibility of energy renovation questionable' (Teni et al., 2019, p. 11). Therefore, one research questioned whether renovations of such buildings 'were implemented with the aim to reduce energy consumption, or to improve the low standard of housing' (Matosović & Tomšić, 2018a). The refurbishment of historical buildings presents a particular challenge as these need to be insulated from the inside to protect the façade (Zagorskas et al., 2014). However, the energy savings can be significant: Blecich et al. (2016) reported an 80% reduction in energy use in Kršan Castle in Croatia with an estimated payback period of 10–16 years.

The second main topic identified in the existing literature on energy efficiency in the CEE region connected to insulation is window replacement. While highly fenestrated facades reduce lighting costs, they increase heating and cooling costs. The size of the window therefore needs to be balanced, and wall orientation is important as well (Motuziene & Juodis, 2010). On the other hand, windows enable energy harvesting during the winter season, while appropriate use of shade can help to achieve energy efficiencies all year long (Košir et al., 2018). Both the windows themselves and their cardinal directions thus have an important effect on a building's overall energy consumption (Kull et al., 2015).

Retrofitting windows is not as effective as wall or roof insulation, mostly because of the high investment required and slow repayment. However, retrofitting windows brings added value in other areas (market value of the building, improved air quality etc.; Kaklauskas et al., 2006). It has been argued that in the cold Estonian weather, small triple-glazed windows along with 200-mm wall insulation are the cost-optimal solution (Pikas et al., 2014) and that bigger windows were optimal only with quadruple window glazing (Thalfeldt et al., 2013). However, research in Lithuania claimed that replacing all the windows in apartment buildings with any available new windows with PVC (polyvinyl chloride) frames (even with double glazing) would reduce consumption by at least 30% (Staniūnas et al., 2013). In addition, fitting roller blinds on double-glazed windows can improve energy efficiency. Internal blinds can reduce heat loss by 33% and external ones by 45% (Oleskowicz-Popiel & Sobczak, 2014). In Estonia, a combination of automated external blinds and quadruple glazing reduced energy consumption the most, although it was not the most cost-effective (unlike triple glazing) and the blinds 'were not a feasible solution in a 20-year perspective due to high cost' (Thalfeldt et al., 2017, p. 686).

Heating Source

The second topic discussed in the literature on improving the energy efficiency of buildings in the CEE region is connected to heating sources. These studies examine two main types of heating systems: district heating systems (DHS) and individual heating systems. Discussions on heating systems in the CEE countries generally focus on the deployment of renewable energy sources (RES) to reduce carbon dioxide (CO_2) emissions. New heating sources are also discussed with the aim of identifying the best possible solutions to meet EU and national climate goals.

First, existing research, to a large extent, focuses on the possibilities of decarbonising DHS by deploying RES. This research demonstrates that RES would bring not only environmental but also economic benefits (Huculak et al., 2015) as they are more cost-effective than natural gas (Pavičević et al., 2017). For example, geothermal energy has the potential to improve not only the cost-efficiency but also the energy efficiency of DHS as such (Lipan & Dimitriu, 2013). Slovenian research (Urbanci et al., 2016) concluded that geothermal energy could potentially be used as a base load in DHS, but that individual systems would be more cost-effective (Stegnar et al., 2019).

Solar energy is another promising source that could potentially be used in DHS, even in northern countries (Delle et al., 2019) and is economically comparable to natural gas (Soloha et al., 2017). There is an ongoing discussion on the efficiency of solar thermal collectors and photovoltaic (PV) panels. While PV thermal hybrid solar collectors could be used in DHS in CEE (Pardo García et al., 2017), solar thermal collectors and an accumulation tank are a better alternative to a gas boiler than solar PV panels with heat pumps (Polikarpova et al., 2019). In another example from northern CEE countries, 'the scenario implementing low-temperature district heating with solar PV showed the best score for environmental performance' (Feofilovs et al., 2019, p. 272). However, Dytczak and Ginda (2006) argue that the best solution very much depends on the financial abilities of the municipality. Wind energy was explored as well, leading to the conclusion that DHS, in combination with heat pumps and heat storage, can enable flexible wind power use (Bazbauers & Cimdina, 2012). Similarly, a model using data from Wroclaw in Poland showed that wind power can be used in conjunction with a geothermal heat source (Ciapała et al., 2019).

Several studies argued that to enable efficient renewable use, the replacement or refurbishment of the old district heating pipes is crucial (Čulig-Tokić et al., 2015). Future improvements should, therefore, focus not only on implementing RES in heat production but also on reducing the supply and return temperature and addressing pipe conditions (Volkova et al., 2018).

Cogeneration is another important topic relating to research on DHS in CEE. According to Directive 2004/8/EC on the promotion of high-efficiency cogeneration, cogeneration is essential to meeting the EU's climate goals. Indeed, combined heat and power (CHP) cogeneration has been shown to improve energy efficiency in buildings (Streimikiene & Baležentis, 2013). While a Polish study demonstrated that the share of cogeneration in DHS with a network hot water tank improves the cost efficiencies of cogeneration (Gładysz & Ziębik, 2013), fuel switching possibility enhances CHP efficiency (Wojdyga & Niemyjski, 2012). Wastewater excess heat can also be used in DHS, but investment return depends on 'the distances from the district heating station and the expenditures of the heat pump and pipelines' (Somogyi et al., 2018, p. 712). From the economic perspective, it is argued that integrating CHP in district heating requires financial support from public authorities due to a long payback period (Lončar & Ridjan, 2012).

Second, household utilisation of RES for heating has also been examined in the literature, which focused mainly on solar energy and revealed its competitiveness over fossil fuels. Lacko et al. (2014) demonstrated the feasibility of a combined energy system based on solar and wind power with hydrogen storage and found that it was economically cost-effective compared to fossil fuel use. Similarly, a performance analysis of a simulation of a solar thermal heating and cooling (SHC) system in Croatia showed potential 'recovery up to 53% of waste condenser and absorber heat, reduc[ing] cooling energy price by 15%' (Delač et al., 2018, p. 489). Another simulation of a family home in Wroclaw, Poland, showed that it is feasible to construct a heating installation based on the long-term accumulation of thermal energy from a solar collector (Nemś et al., 2018). Moreover, a study of an apartment building in Latvia claimed that over time, the required investment in solar collectors should decrease and their efficiency should increase (Prodanuks et al., 2019). A thermal solar system for single-building heating in Croatia can save an average of 50–60% annual natural gas energy (Hornung et al., 2010). A Slovenian case demonstrated the advantages of a thermochemical storage system over seasonal sensible-heat storage (Mlakar et al., 2019).

In a nine-year research project in Slovenia, 'the air-to-water heat pump operation demonstrates that in terms of energy efficiency the pump is the most appropriate for heating the energy-saving house' (Marcic, 2004, p. 191). Heat pumps greatly contribute to climate goals not only in individual houses but also in larger building complexes, as demonstrated in a Croatian hospital complex (Pavković et al., 2012) and in Lithuania, where 'equipping a new family house with a heat pump instead of an oil burner saves (in average) more than 4 tonne of GHG emissions and around 50% of primary energy per year' (Gaigalis et al., 2016, p. 856). Moreover, in the (cold) climatic conditions in Latvia, air-to-water heat pump operating costs were lower in comparison to gas, diesel or electricity (Kazjonovs et al., 2015).

Wood briquettes are another potential fuel (Stolarski et al., 2016), even as a fossil fuel alternative (Stolarski et al., 2013), as experience from Poland suggests. However, residual biomass pellets could not economically compete against brown coal in Czechia (Vávrová et al., 2018). When it comes to the use of biomass, it is especially important to focus on efficient biomass combustion boilers 'in the context of synergy between the goals of a national climate policy and the clean air policy' (Kudrenickis & Klavs, 2014, p. 23). Indeed, air pollution in the CEE region is often connected to the improper use of biomass, mainly firewood.

Research in a residential building near Krakow has further shown that it is possible to achieve a high share of renewables through the hybrid installation of four heating devices (Pater, 2019). For instance, it was demonstrated that combined solar and heat pump systems show a better performance than stand-alone heat pump systems (Januševičius & Streckienė, 2013). Combined solar and biomass systems have the potential to reduce GHG emissions in cold climates as well, as demonstrated in Lithuania (Katinas et al., 2013), and could replace natural gas on economic and environmental grounds (Zandeckis et al., 2012). In a much warmer climate (Croatia), a solar hot water system (with a biomass boiler as the back-up heater), when compared to a gas-boiler system, can save approximately 30% of primary energy delivered (Berković-Šubić et al., 2014). In a Romanian study, it is argued that replacing traditional gas boilers with gas condensing boilers coupled with heat pumps can significantly reduce CO_2 heating emissions (Cîrstolovean, 2015, p. 11).

Policy

With regards to the literature on energy and buildings in CEE dealing with the policy context, we identified three scope areas around which the analysed papers revolved: energy poverty, behavioural measures and energy efficiency policies. This literature examines how decisions connected to (improvement of) energy efficiency of buildings are made at various levels – individual, national, EU etc. The scope of analysed papers is limited to case studies or small-scale regional comparations. Their common thread is the focus on the importance of the political and economic landscape, the post-Communist legacy, as well as the lack of systematic, complex and targeted policies that do not effectively deal with issues such as the high level of risk of energy poverty, ineffective energy consumption behaviours or low energy efficiency rates of the building stock.

Energy poverty

First, the aspect of energy and buildings in CEE that is in the foreground of research on the region is energy poverty. This is related to the broader context of the EU's policy-making mechanisms, such as limitations in initiating and developing related EU policies (Kyprianou et al., 2019) and their ineffective implementation nationally in the absence of a coordinated and targeted approach (Bouzarovski et al., 2012). The lack of a systematic, complex and evidence-based approach leads to only 'embryonic' policy discussions on how energy poverty affects different vulnerable groups (Bouzarovski, 2014). The specific nature of the post-Communist context and the economic transitions therefore constitutes a specific cause of the energy poverty in CEE, particularly given the insufficient social safety net (Buzar, 2007), technical and institutional constraints physically limiting the options for reducing energy consumption (Tirado Herrero & Ürge-Vorsatz, 2012), and economic and institutional landscapes of the CEE region (such as systemic legacies of socialist central planning, the legacy of inefficient housing stock or energy dependence on Russia; Bouzarovski et al., 2016). Karpinska and Śmiech argue that approximately one-fourth of the region's population is exposed to 'hidden energy poverty', a concept that is able to look more closely at the challenges households face to pay their energy bills (2020). Traditional 'energy poverty' is 'hard to detect because of abnormally low energy expenditures in many households' of the CEE region that are 'experiencing challenges of making ends meet [and therefore] prioritise other basic needs and cannot afford to maintain a comfortable temperature inside' (Karpinska & Śmiech, 2020, p. 2). The resulting low share of energy bills on total household expenditure is thus not an indicator of 'non-poverty' but of other challenges that are not captured by 'energy poverty'.

The literature is equally diverse in identifying the consequences of energy poverty in the CEE region and their policy implications. First and foremost, energy poverty represents one of the causes of the deep systemic social injustices resulting from falling incomes combined with rising energy prices and the state of the housing stock. It is argued that instead of income-based solutions, policymakers should focus on housing and demography-related vulnerabilities (Bouzarovski & Tirado Herrero, 2017). Moreover, energy poverty also has a significant impact on individual perceptions of life satisfaction, well-being and, to a certain extent, health (Druică et al., 2019; Robić & Ančić, 2018; Thomson et al., 2017). That predetermines the difference in strategies for dealing with energy poverty: for instance, increasing the use and accessibility of renewable energy sources as a means of reducing household energy expenditure (Rajchel, 2017) or targeting energy poverty policies at all levels of the energy supply chain (Hiteva, 2013).

Behavioural measures

Second, behavioural and consumption-targeted research focuses on behavioural measures, highlighting the energy efficiency potential – and also shortcomings and limitations – of various consumer-oriented policies in the region. For instance, awareness, knowledge and understanding of the potential for energy savings and the wider implications have been shown to have a significant impact on consumer behaviour (Streimikiene, 2015). Heating controls (Kaminska, 2019), cultural and psychological factors such as greater public openness to innovation (Simanaviciene et al., 2017), the impact of changes to the administration of the energy supply (Vranayova et al., 2007) and the effect of energy performance certificates on consumption (Popiolek & Kateusz, 2017) also play a role. So do the policies aimed at changing consumer behaviour that potentially play a role in increasing energy efficiency through tailor-made information dissemination, marketing interventions and social messaging (Volochovic et al., 2012). In this case, even basic everyday activities can be a crucial target for the policy interventions that optimise the energy efficiency of buildings, as the analysis of window opening and closing in Hungarian schools shows (Deme Belafi et al., 2018).

However, other studies point to the limited impact of education and awareness-raising campaigns on target groups of diverse socio-economic, demographic, attitudinal and lifestyle characteristics and building types. Positive environmental attitudes are not sufficient to alter consumer behaviour over the long term in the absence of knowledge about how to transform such attitudes into action (Kowalska-Pyzalska & Byrka, 2019). Moreover, there is a lack of 'clever and sophisticated marketing' that would successfully explain the complexity of energy saving to the wider public (Makijenko et al., 2016). Other limitations can be observed on the policy-making level, in particular policies based on models that take no account of socio-economic development, climate, composition and age structure of the existing building stock (Vásquez et al., 2016). End-user knowledge is key if the authorities are to develop adequate policies, for instance, to promote and increase the use of renewable energy among the population (Ropuszyńska-Surma & Węglarz, 2018).

Besides, it has been demonstrated in nine Organisation for Economic Co-operation and Development (OECD) countries that energy-efficient behaviour is more prevalent among people concerned about the environment (Urban & Ščasný, 2012). There are several case studies from across the region that offer support for this claim. The evidence from European countries including Poland and Romania shows that income level and energy efficiency are linked, supporting the argument that more targeted support for low-income households is needed (Schleich, 2019). Although effective micro-grid management plays a key role in reducing energy consumption across the entire household sector (Kott & Kott, 2019) and energy consumers decide to use smart energy management systems for the financial benefits in the form of lower energy bills but also the environmental benefits (Kowalski & Matusiak, 2019), smart device penetration is still low (Gluszak et al., 2019). While people are willing to purchase smart energy-saving devices, the main obstacle is their price (Rihar et al., 2015).

Similarly, an analysis of residential buildings in Lithuania shows that energy innovations are more effective than energy savings obtained through changes in consumer behaviour (Štreimikienė, 2014). Still, behavioural change is important and should be encouraged through specific policies, such as household energy audits, more informative energy bills or information campaigns (Belafi et al., 2017; Streimikiene & Volochovic, 2011). An analysis of the Northern Great Plain Region in Hungary shows that despite the lack of information, the population is positively disposed towards energy efficiency solutions, indicating the high potential of more targeted campaigns and promotions that would potentially deliver the needed information on technological possibilities and solutions and could ultimately bring about the necessary behavioural changes (Pénzes et al., 2014). Moreover, one Croatian study demonstrated that proper enforcement of the laws on new and renovated buildings is a key element in achieving energy savings (Pukšec et al., 2013).

Energy efficiency policies

The third identified scope of literature in this category is energy efficiency policies. Here, the focus is predominantly on the success of these policies. These studies highlight shortcomings in current energy efficiency policies and their evaluation, such as the incorrect and insufficient energy certification of building renovations (Biekša et al., 2011) or lack of comprehensive strategic plans and concrete objectives (Bíró-Szigeti, 2014). At the same time, they provided suggestions for improving these policies, for instance, by inputting household consumption characteristics and investment choices into energy efficiency policy models (Matosović & Tomšić, 2018b) or evaluating the cost of changing energy policies (Mrówczyńska et al., 2018). Other limitations in this area included the difficulty of following the EU legislation on energy efficiency, which applied mainly to local authorities attempting to comply with EU requirements (Bazan-Krzywoszańska et al., 2016). Other cultural and institutional barriers to building performance evaluations (Stevenson & Baborska-Narozny, 2018) included the lack of a systematic, coherent approach to implementation, coordination and timing (Abolt-ins & Blumberga, 2019) and the ability to overcome market development barriers in residential buildings (Labanca et al., 2015).

Energy efficiency policies have a positive effect on tax revenues, job generation, investments and economic growth (Mikulić et al., 2016; Rodenburg, 2006) and also reduced emissions (Dagilit & Juknys, 2012; Stroe & Leca, 2015). The post-Communist transitions including changes to the legal environment are thought to have an impact on energy efficiency trends in CEE. Such changes relate to, for instance, regulations (Poputoaia & Bouzarovski, 2010), national subsidy systems (Romagnoli et al., 2014) and inadequate funding schemes (Nižetić, 2017).

Results and discussion

It is characteristic of Central and Eastern Europe that many buildings are not insulated, which is an energy consumption problem, but at the same time offers huge potential for energy savings (Lakić et al., 2020). The existing research on the region focuses on two main issues – wall and window insulation, which other research also identified as 'the two main agents of energy efficiency in buildings' (Najjar et al., 2019, p. 1378). However, roof insulation has been identified as an important part of a building's envelope from an energy efficiency perspective, especially when it comes to cooling (Ran et al., 2017). Wall insulation has both environmental (lower CO_2 emissions) and economic (lower energy bills) advantages for both private and public buildings, especially insulation that meets the latest energy standards. While this finding does not differ from the rest of Europe (Gulotta et al., 2021), what is specific for the CEE region is the proclaimed need for public support of retrofitting. It has been argued that stimuli are needed as high insulation costs were identified as a barrier to insulating privately owned homes.

Several studies identified air quality problems following insulation, an issue that should be addressed in the preparatory phase of insulation. This is in contrast with results from North-Western Europe, where research on air quality following insulation found mixed results, with decreased air quality linked especially to countries (Lithuania) that we included in the CEE region (Simpson et al., 2020). According to existing research, replacing windows is less cost-effective than wall insulation due to higher costs. However, other benefits (increase in property value, improved aesthetics of the building etc.) should also be considered when investing in window replacement. The research supports fitting triple or even quadruple-glazed windows and claims that even the most affordable windows with PVC frames significantly decrease energy consumption. Similar results for windows were also found in other regions (Chen et al., 2020), with double-glazed windows considered especially suitable for warmer climates (Gaterell & McEvoy, 2005). Our results regarding the CEE region are thus in line with results from other regions when it comes to the effect of window replacement on the energy consumption of buildings.

Heating systems offer untapped potential for renewables deployment, which is a crucial part of clean air policies and EU climate goals. Biomass has been widely used in the region for heating purposes, but its poor utilisation is connected to problems of air quality – a phenomenon present especially in the CEE region (Ozgen et al., 2021). Therefore, the research focuses on other forms of renewables that have been underdeveloped within the heating system: solar, geothermal and heat pumps that could be developed on a large scale for both district and individual heating systems. Existing research has so far dedicated the most attention to the use of solar energy and fairy little to the integration of biogas into the heating system. While solar has been demonstrated to be an economically competitive source even compared to fossil fuels, seasonal heat storage is important for the further expansion and use of this type of energy. When integrating renewables into district heating systems, refurbishing old district heating pipe networks is crucial for improving energy efficiency. The research also recommends hybrid installations to gain even better results, such as solar and heat pump systems or solar and biomass systems. Although initial investments are high, a renewable-based heating system can be more cost-effective than a fossil fuel one.

Energy poverty is a crucial issue for CEE as it contributes to the systematic social injustices observable in the region. These are primarily related to the old energy-inefficient housing stock of the Communist era, but the impact and consequences of the economic and political transformations following the democratic revolutions play a role, too. Such legacies and policy settings, including technical, legal, economic and institutional restraints, affect the extent to which CEE countries are ready, willing or even able to implement policy changes to improve building energy efficiency and optimise energy consumption. Research shows that CEE countries have high energy demand and consumption and lack viable and effective solutions as well as financial resources. At the same time, the lack of data and evidence-based policy decision-making and implementation in CEE countries is another huge weakness, particularly when it comes to designing and implementing policies that are dependent on or closely tied to behaviour and consumption. According to existing literature, the various aspects of the post-Communist legacy, along with the non-systemic and non-targeted policies that fail to identify and help groups that are the most vulnerable to energy poverty, is therefore the key common feature of the region.

Conclusions and policy implications

This paper examined existing research on potential energy efficiency improvements to buildings in Central and Eastern European countries which share a common Communist legacy of poor energy efficiency. The first step in our research was to create a main database containing all the research articles on energy in the CEE region published between 2004 and 2019 and identify those related to buildings. Less than 15% of the research is related to buildings, which is arguably a small proportion given the significance of buildings for the energy mix – both in terms of energy consumption and CO_2 emissions. We then identified three main topics in the research on buildings where potential improvements can be made to the existing building stock's energy efficiency – insulation, heating source and policy. These were represented evenly across the research (we identified 91, 88 and 101 articles, respectively). After providing a descriptive overview of these articles, we examined their content from the perspective of energy efficiency improvement.

We consider our results presented in the previous section useful for several generalisable reasons beyond the specificities of the CEE region identified above. To the best of our knowledge, this is the first attempt to systematically examine the existing literature on the energy efficiency of buildings in the CEE region. Therefore, our results present an important data-based observation of the state of knowledge about the region and the energy efficiency of its buildings. Moreover, this knowledge can serve as a starting point for future research that can be based on our findings, based on a systematic study of existing literature – not only in the areas mentioned below. Thanks to its systematic nature, our research can also be used to identify gaps in existing research as it covers issues examined by the literature and can therefore be helpful to identify areas that have not been studied yet.

Furthermore, our findings have important policy implications for improving building energy efficiency in Central and Eastern Europe, as well as beyond. First, the existing research has shown that wall insulation and window replacement could significantly reduce building energy consumption and thus reduce the costs of heating and cooling, as well as decrease the emissions of buildings. However, such investments are out of reach for many households, especially in the CEE region, and funding should be provided for those who need them. While various national subsidies exist in CEE countries, they are often non-systemic and/or poorly designed (Kiss, 2022). Moreover, future schemes should prioritise deep renovation, which is not only a suitable method for decarbonization thanks to increased energy savings but is also a crucial step before fuel switching.

Second, there is huge potential for renewable use in heating systems, which is crucial for the EU's climate and energy goals, environment and energy security. While biomass remains a traditional and viable option (especially in remote areas) and CEE countries plan its further use (Bartek-Lesi et al., 2020), it is essential that the utilisation of renewables extends beyond biomass. Using other renewables in heating systems – in particular, solar thermal collectors and geothermal energy – would help to achieve 2030 renewables targets, which for some CEE countries are difficult to meet (Mišík & Oravcová, 2022). Moreover, it would help these countries deal with air quality problems, as cleaner and more efficient heating systems make a big difference in air pollution as well (EEA, 2023).

Both measures (refurbishment and change of heating source to use renewables) are key to improving energy security. This is particularly true for CEE countries, as their heating systems are, in many cases, dependent on imported natural gas. If the EU wants to reduce natural gas consumption and eliminate dependency on Russian supplies in the mid-term (European Commission, 2022a), refurbishing building envelopes will be an important step not only in residential buildings but also in non-residential as well. Moreover, focusing on renewables will help them to reduce this dependence and weaken the connection with fossil fuel prices.

Third, governments need to tackle the energy poverty in CEE systematically. That would improve wellbeing and encourage investment in energy efficiency policies to reduce energy consumption and/or switch to cleaner (domestic) energy sources. While initial costs may be high, these should be viewed as long-term investments rather than subsidies and should be encouraged more frequently. As observed during the recent energy crisis, governments tended to opt for subsidies instead of providing targeted support (Murarașu et al., 2023; Sgaravatti et al., 2023). However, this is not sustainable in the long run. More tailor-made information campaigns are needed to raise public awareness of the potential energy efficiency measures that can be made in their own homes and thereby reduce EU dependency on third-country energy supplies.

This paper has several limitations. First, since we examined published papers, our research does not include analyses of the energy efficiency of buildings linked to the current energy crisis. However, we hope to offset this limitation by providing policy implications. Future research should focus on changes to building stock connected to the ongoing crisis that started in mid-2021. Second, this paper focused on a single region – Central and Eastern Europe – and therefore, its conclusions are primarily applicable to this geographic area, characterised by a specific type of building stock with a strong Communist legacy. Notwithstanding, we believe that the general findings and implications of our paper can also provide important suggestions regarding the energy efficiency of buildings in the rest of the EU and beyond. Indeed, contrasting our results with the situation in the rest of the EU would bring very important results for the development of the regulatory framework existing within the union. Future research should therefore compare our results with the rest of the EU (for example, Bauer et al., 2021). Third, while the paper has highlighted, in several places, differences between residential and non-residential buildings (especially in the 'Insulation' section), we did not go deeper into this issue as energy efficiency is challenging for both types of buildings within CEE. Future research should, therefore, examine whether there are specific challenges of these sub-sectors of buildings in the region or if challenges – and therefore also solutions – are universal. Fourth, by focusing on the literature on buildings, the paper does not engage with legislative frameworks and policy objectives existing at the national or European level, directly or indirectly connected to the energy efficiency of buildings. Therefore, future research should look into those initiatives and rules that impacted or failed to impact the energy efficiency of buildings in the CEE region in order to identify best practices, suitable policies or missed opportunities.

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Declarations

Conflict of interest The authors declare no competing interests.

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