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Strategy of Energy Poverty Reduction in the Czech Republic

Doctoral Thesis

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DECLARATION

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Title of dissertation: Strategy of Energy Poverty Reduction in the Czech Republic

I declare that I have independently prepared the dissertation thesis mentioned, under the guidance of my supervisor, doc. Ing. Jiří Karásek, Ph.D. The utilized literature and other materials are listed in the bibliography.

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signature

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Abstrakt

Disertační práce je zaměřena na problematiku energetické chudoby v České republice. V souvislosti s plněním stanovených evropských cílů v energetické a klimatické oblasti dochází ke změně technických a technologických vlastností budov, mění se nejen nová výstavba, ale je i vysoký zájem o změnu stávajícího bytového fondu. Ačkoliv se evropská a národní legislativa snaží podporovat trend energeticky efektivních budov, může docházet k vzniku určité skupiny domácností, které budou z tohoto trendu vyloučeni. Vyloučení této skupiny hrozí především z důvodu neschopnosti změnit jejich aktuální situaci spotřeby energie a s tím související finanční náklady spojené s bydlením. Tuto situaci nedokáží změnit ani vlastními silami, ani za pomoci stávajících dotačních programů.

Cílem práce je zdokumentování současného stavu problematiky energetické chudoby v České republice, identifikace dopadů energetické chudoby na domácnosti. Stanovení ohrožených skupin, které jsou energetickou chudobou zasaženy, nebo by je energetická chudoba mohla zasáhnout z důvodu budoucího vývoje cen energií, stavebních materiálů a prací.

V rámci práce jsou vyhodnoceny legislativní kroky, které byly prozatím uskutečněny pro snížení energetické chudoby a jejího dopadu na domácnosti. Práce obsahuje návrh programu a jeho zaměření tak, aby co nejvíce přispěl ke snížení energetické chudoby.

Součástí disertační práce je vytvoření návrhu strategie pro snížení energetické chudoby v České republice v kontextu současné společnosti a technologických možností. Cílem návrhu této strategie je identifikovat a navrhnout možnou implementaci opatření, která přispějí k efektivnímu a udržitelnému snižování energetické chudoby. Práce zkoumá hlavní faktory a příčiny energetické chudoby a navrhuje strategické přístupy a opatření, které zahrnují zlepšování energetické efektivity budov, podporu obnovitelných zdrojů energie, finanční pomoc zranitelným domácnostem a rozvoj vzdělávacích programů zaměřených na energetickou efektivitu. Disertační práce poskytuje podklady pro vypracování efektivní strategie, která přispěje k dlouhodobému snižování energetické chudoby a zlepšení životních podmínek domácností postižených energetickou chudobou.

Klíčová slova:

Energetická chudoba, energetická účinnost, programy podpory, strategie proti energetické chudobě, výdaje domácnosti, potřeba tepla na vytápění

JEL: Q41 – Poptávka a nabídka, Ceny
Q43 – Energie a makroekonomie
Q48 – Energie – Vládní politika

Abstract

The dissertation focuses on the issue of energy poverty in the Czech Republic. In the context of meeting the established European energy and climate goals, there are changes in the technical and technological characteristics of buildings. This affects not only new construction but also generates significant interest in the transformation of the existing housing stock. Despite efforts of European and national legislation to promote the trend of energy-efficient buildings, a certain group of households may be excluded from the trend. The exclusion of this group primarily stems from their inability to change their current energy consumption situation and the associated financial costs related to housing. The situation cannot be altered either by their own efforts or through existing subsidy programs.

The objective of the work is to document the current state of energy poverty in the Czech Republic, identify the impacts of energy poverty on households, and determine vulnerable groups that are affected by energy poverty or could be affected due to future developments in energy prices, building materials, and labour.

The dissertation evaluates legislative measures that have been taken so far to reduce energy poverty and its impact on households. It includes a proposal for a programme and its focus to contribute as effectively as possible to reducing energy poverty.

An integral part of the dissertation is to propose a strategy for reducing energy poverty in the Czech Republic within the context of contemporary society and technological possibilities. The aim of this strategy proposal is to identify and suggest possible implementation of measures that will contribute to the efficient and sustainable reduction of energy poverty. The work examines key factors and causes of energy poverty and proposes strategic approaches and measures, including improving building energy efficiency, promoting renewable energy sources, providing financial assistance to vulnerable households, and developing educational programs focused on energy efficiency. The dissertation provides the foundation for the development of an effective strategy that will contribute to the long-term reduction of energy poverty and improvement of living conditions for households affected by energy poverty.

Key words:

Energy poverty; Energy Efficiency; Support programs; Strategy against energy poverty; Household Expenses, Heating demand

JEL: Q41 – Demand and supply, Prices
Q43 – Energy and the Macroeconomy
Q48 – Energy - Government Policy

Obsah

List of used symbols and abbreviations

CHP	Combined Heat and Power
COP	Conference of Parties (related to climate change)
CR	Czech Republic
EC	Energy Community
EE	Energy Efficiency
EED	Energy Efficiency Directive
EP	Energy Poverty
EPBD	Energy performance of buildings directive
EPC	Energy Performance Contract
EPCe	Energy Performance Certificate
ESCO	Energy Service Company
EU legislation	European Union legislation
EU targets	European targets
EU	European Union
GHG	Greenhouse Gas
GWP	Global Warming Potential
HES	Home Energy Score
HVAC	Heating, Ventilation, and Air Conditioning
NGO	Non-Governmental Organization
PV	Photovoltaic
R&D	Research and Development
RES	Renewable Energy Sources

1. Motivation

The chosen topic of the dissertation is the economics of energy in buildings. Since it is a very broad subject, only a part of it has been selected for the focus of this work. Attention in the thesis has been exclusively devoted to residential buildings. The primary focus of the selected part is the issue of energy poverty. There has been a growing interest in this topic worldwide in recent years, although in the Czech Republic, it has not been addressed to the extent that, in my opinion, it should be. The main goal of this work is to expand knowledge about energy poverty not only within the scientific community but also to find suitable ways to inform the general public and, in particular, households affected by this issue, and it is also aimed at providing appropriate solutions.

Energy poverty has recently begun to be discussed in the Czech Republic and throughout Europe. Over the years, household comfort has been steadily increasing, the number of appliances is growing, and there is a constant need for thermal comfort, heating, cooling, and air conditioning, all of which increase the energy needs of households and raise household expenses. It is possible that the number of households affected by energy poverty will continue to rise.

Households affected by energy poverty do not have the financial means to invest in the building they live in, enabling them to undertake renovation work, particularly construction work, to improve energy efficiency and reduce household heating expenses. In conjunction with developments in the energy sector on a global scale and the adoption of European goals, there is expected to be pressure for energy prices to rise.

The Czech Republic has committed to achieving its energy-related goals gradually by 2020, 2030, and 2050. The focus of these goals primarily concerns final energy consumption. To meet these objectives, a number of supportive programs have been announced. These programs are intended to assist residents in implementing energy-saving measures. The most common goal of these programs is to support physical changes to the building's properties, primarily focused on improving the building envelope, replacing doors and windows, or upgrading outdated heating sources. However, these programs provide support or partial financing, with most of the costs borne by households themselves. The issue arises when these households do not have the financial means available. They are unintentionally excluded from the trend of building renovation and increasing energy efficiency in buildings. Their situation will worsen over time.

Energy-poor households represent a relatively extensive area where significant energy savings can be achieved. However, a different approach is needed to achieve these savings than is currently being provided. Therefore, the goal is to provide basic information about

energy poverty and help create a strategy for reducing energy poverty in the Czech context. This dissertation is designed to summarize essential information needed for the adoption of the Strategy for Reducing Energy Poverty by Czech legislation. The work provides proposals for a possible strategy, its action plans, and related support programs, specifying household groups that need to be addressed and the potential benefits resulting from this assistance, not only for households but also for the state.

1.1 Current situation of the addressed issue

The issue of energy poverty appeared in the professional community shortly before 2000. In 2001, the UK Fuel Poverty Strategy 2001 was developed in the United Kingdom. In the continental part of the EU, energy poverty is determined by total expenditure for all types of energy used by households. An overview of the EU's activities in the fight against energy poverty can be found on the European Commission's website. This site shows that other EU Member States are also addressing the issue (EC, 2021).

The topic has not yet been sufficiently addressed in the Czech academic environment, which can be inferred from the absence of professional publications in databases. Several popularization articles have appeared in the commercial sector and a detailed study on the potential of energy savings in buildings in the Czech Republic commissioned by the manufacturer of mineral wool insulation.

Several forms of state aid using EU operational programs address the issue of energy poverty. The most important of these are the EFEKT programme under the responsibility of the Ministry of Industry and Trade and the OP Environment under the responsibility of the MoE providing so-called cauldron subsidies.

Over the last few years, the issue of fuel poverty has become more prominent in the context of a series of events, mainly linked to the rise in energy prices and the increase in the cost of construction works, which are closely linked to energy saving measures.

There has been an opening of subsidy programmes in the Czech Republic that help to reduce energy poverty, their benefits, disadvantages and overall impact are analysed further in the text. From the above, I conclude that the topic resonates in the commercial sphere and that the academic world should reflect it.

1.2 The relevance of the energy poverty topic to the focus and scientific activity of the department of Construction Management and Economics

Energy poverty combines economic, technical, social, and environmental aspects that have a significant impact on society. Thus, issue related to the economics and the construction are crucial in addressing energy poverty. From an economic perspective, it is possible to analyse the costs and benefits of various strategies for reducing energy poverty and the efficiency of investments in energy efficiency and renewable energy sources. The construction aspects encompass improving the energy efficiency of buildings, including insulation and efficient heating and cooling systems. The energy approach involves investments in renewable energy sources and modern technologies that reduce energy demand. By combining these approaches, a sustainable and effective solution to energy poverty can be achieved, enhancing living conditions and reducing social inequalities.

Addressing energy poverty requires innovations in the field of energy, energy economics, building energy efficiency, and the construction industry. This topic is directly aligned with the focus of the Faculty of Civil Engineering and the department of Construction Management and Economics.

2. Definition of study area

The work focuses on a comprehensive mapping of the energy poverty situation in the Czech Republic and the identification of probable household types affected by energy poverty. To obtain more accurate information, household categorization based on geographical distribution and the size of municipalities in which they are situated has been performed, while also confronting them with local conditions and influences causing energy poverty.

Energy poverty can be perceived not only from a purely economic perspective but also has a significant impact on the environment. In buildings inhabited by households affected by energy poverty, it's possible not only to implement suitable measures to reduce energy consumption but also to mitigate harmful emissions. Emphasis has been placed on identifying improvements in living conditions, which subsequently have economic implications.

The work includes calculations of thermal energy savings achieved through changes in the physical properties of the envelope constructions of properties falling within the scope of energy poverty. The most suitable measures that significantly save energy and households' finances will be determined. Additional potential energy-saving measures will be addressed, such as replacing the existing heating system, especially by changing heat sources, distribution, and radiators. After quantifying the necessary investments and subsequent heat savings, the appropriateness of targeting subsidy programs for these energy-saving measures can be determined.

Evaluation of existing support programmes

In the Czech Republic, subsidy programs aimed at supporting the reduction of energy expenses have been running for several years. However, the configuration of their conditions is not entirely suitable for addressing the issue of energy poverty. Therefore, the work focuses on evaluating the current programs and their impact on households in the Czech Republic, particularly in terms of their effect on energy poverty.

Energy poverty reduction programme

The main objective of the dissertation is to propose possible measures against energy poverty in the Czech Republic, including a proposal for a support programme or modification of the existing one to contribute to reducing energy poverty, which is becoming an increasingly urgent topic. Possibility of increasing the absorption capacity of investment grant titles in the area of energy efficiency and in the area of RES utilization.

The project outputs should serve as a basis for addressing selected parts of the EED, in particular measures against energy poverty under Article 7. A significant part of the work

should support the development of a strategy for reducing the impacts of energy poverty in the Czech Republic.

Draft strategy for reducing energy poverty in the Czech Republic

One of the outputs of the dissertation is a proposal for a strategy to reduce energy poverty in the Czech Republic. The strategy includes an analysis of the current situation and an assessment of the state of energy poverty. Data about households, energy, and other relevant factors are collected. The analysis helps to better understand the extent and depth of the issue.

The strategy encompasses the matter of defining energy poverty and related indicators for its measurement. Mechanisms for monitoring and assessing the results and effectiveness of the strategy are proposed to facilitate ongoing adaptation and enhancement in response to the evolving situation.

Based on the analysis and definition of energy poverty, specific goals for reducing energy poverty are set. These goals should be Specific, Measurable, Achievable, Relevant, and Time-bound (SMART). Strategic measures and policies to achieve these goals have been developed based on the established objectives.

The development of the strategy to reduce energy poverty requires coordination and collaboration among various stakeholders, including governmental bodies, non-governmental organizations, energy companies, the academic community, and other relevant entities. Joint efforts and coordination are crucial for the successful implementation of the strategy. Key partners to be coordinated in addressing this issue are outlined in the strategy proposal.

2.1 Definition of essential research questions

A: How to reduce energy poverty in the Czech Republic and how to help households already affected by energy poverty?

- Developing a strategy to tackle energy poverty.
- Developing a methodology for designing appropriate measures for households affected by energy poverty.

B: What are the impacts of energy poverty on the household and the state?

- What are the costs of implementing austerity measures?
- What is the potential for energy savings in this area?

To address the two fundamental questions, the following sub-questions were posed:

1) What is the state of energy poverty in the Czech Republic?

Survey on the local conditions, numbers of households at risk, types of households and dwellings in which they live.

2) What households are affected by energy poverty?

Are poor households particularly at risk due to lack of finance or a family with an average income but living in a low-quality apartment? Are households in a village or town living in an apartment or family home more at risk?

3) Is energy poverty of the same type in the Czech Republic as in other countries?

In every country there are different customs, whether the way of life, especially the way of heating, the size of the flats in which they live, energy prices, building technology that affects the loss of the building, all this can affect the form of energy poverty, change not only numbers of households at risk, but also changing the way to reduce energy poverty.

4) What is the impact of existing grant programs?

Existing programs can also reduce energy poverty in the Czech Republic, it is necessary to ascertain their impact and either strengthen it or find other programs that focus directly on the issue.

5) What measures are appropriate against energy poverty?

Is it sufficient to raise awareness or is intervention in the form of government grants necessary? Or is it a more appropriate solution to support the financing of measures from the banking sector?

6) What benefits can energy savings and expenditure have for households?

Will the selected measures benefit the household? Will the implementation of measures not be burdensome for households, which will ultimately discourage them? What is the best way to motivate households?

7) What benefits can energy savings and expenditure have for the state?

Will it only be to distribute money from grant sources or is it more appropriate to create an investment programme instead of a grant program? What impact will the overall reduction in energy consumption have?

2.2 Expected scientific methods

The dissertation primarily focuses on energy poverty stemming from low energy efficiency in buildings. To evaluate the situation in the Czech Republic, statistical data on residents' incomes and their expenditures on energy comfort was compared. Simplified models corresponding to Czech Republic conditions are also developed within the work. Based on these models, it is possible to determine potential savings achievable through the implementation of a subsidy programme targeting energy poverty. The work aims to gather data illustrating necessary costs, returns, and achieved energy savings, not only for individual households but also for energy companies and the state.

In order to identify an optimal approach to the issue, the system of solutions in European Union countries is evaluated, with a focus on the United Kingdom, which currently has one of the most advanced strategies to address energy poverty. A comparison of household situations is integral to this work, crucial for identifying commonalities and differences in energy poverty between the UK and the Czech Republic.

After identifying disparities in household living conditions, demands, and needs, a programme proposal to alleviate energy poverty has been developed. This proposal integrates conditions specific to the Czech Republic along with insights from abroad, aiming to create an applicable solution for addressing energy poverty in the country.

The work also involves the processing of statistical data that help determine the target household types falling into the category of energy impoverished households or those that may enter this category due to external conditions primarily influencing household energy expenditures.

For calculating the required financial costs and potential energy savings of the created support program, it was necessary to establish model structures. These entities are characterized based on statistical data, describing the homes in which energy impoverished households reside. To compute savings, fundamental features of the structure are altered, and these changes are applied when calculating heat requirements. Individual results can then ascertain what savings can be achieved using this program, and after calculating the expenses of essential structural modifications, the necessary investments can be determined.

The analysis of the transferability of foreign experiences involves collecting relevant information and contrasting it with local conditions - such as prevailing thermal building standards, thermal insulation properties of homes, outdoor temperatures, temperature distribution throughout the year, and household lifestyles.

An analysis of household incomes in the Czech Republic, the share of energy expenditures (heating, cooking, lighting, others), the segmentation of households based on housing types (detached houses vs. apartment buildings), projected price hikes vs. reductions in appliance energy demand (lighting, cooking, heating), anticipated proportion of future household energy expenditures, identifying the most significant energy expenditure category, and the solution's potential contribution, especially considering the impacts of increased self-production of electricity, are all integral parts of the analysis.

2.3 Expected Challenges, difficulties and limitations

The findings of the current state of energy poverty

Detecting the situation is possible either by creating a questionnaire system that would provide accurate data for the households in demand, but it is not possible to query all households and it is difficult to estimate what type of questionnaire to choose to focus on energy-vulnerable households. The second method is based on statistical data, although they are more accessible and already characterize the overall situation in the Czech Republic, but they are also significantly distorted both in the acquisition of information and in the averaging.

Energy poverty is primarily caused by the poor thermal-technical condition of the building, the condition of the heating system and the size of the building, but the household's financial income also has an impact. Consequently, low-income households are particularly at risk, particularly households of individuals, pensioners, single-parent families, or single-income families. It will be very difficult to find out how building types and household types are interconnected in order to identify measures in an appropriate way.

Appropriate programme settings

The programme will need to be set up so that it does not discriminate against anyone, but it is primarily targeted at vulnerable households. The programme must be non-abusive but also accessible.

Development of financial environment

The financial environment has been changing quite rapidly and energy prices have changed significantly in recent years, which means not only the changing situation in household expenditure, but also changes in the environment have to be taken into account for the draft measures. To estimate the development of energy poverty, it is necessary to determine the price of energy in the coming years, which will help in calculating the percentage of households suffering from energy poverty. It is never possible to have an accurate estimate, it will always be distorted or will develop differently than expected.

3. Goals of the Thesis

One of the main objectives of this thesis is to increase awareness of the issue of energy poverty. This topic has recently started to gain more importance, especially due to the instability in the energy market, the increase in energy prices and the efforts to emphasize the use of renewable energy sources and its environmentally friendly production and distribution. The aim of this thesis is to identify the areas that the Czech Republic needs to address more consistently in order to reduce energy poverty as much as possible.

Determination of the current situation

The dissertation includes a description of the current state of energy poverty in the Czech Republic and a comparison with other countries of the European Union and the world. The main focus is on areas that directly contribute to the creation of energy poverty or have an indirect impact on energy poverty. These areas are identified and their impact on the spread of energy poverty is described.

The aim of this work is to further identify vulnerable households. It attempts to consistently describe their current situation and establish the dimensions of their issue. Each household has to be treated as individually as possible, but the aim is to establish the most common model situations that will help to clarify the issue of energy poverty and the possibilities to reduce its impact.

Identification of benefits

The aim of the dissertation is to create a list of benefits that can be achieved in the effort to reduce energy poverty in the Czech Republic. The characterization of the benefits is detailed and divided into two main categories, namely benefits for the household itself affected by or threatened by energy poverty, and the second part is benefits for the state.

The potential benefits of reducing energy poverty in the Czech Republic are described in terms of a reduction in energy demand combined with an increase in the standard of living of the population. In relation to energy savings, the potential for achieving energy savings in relation to meeting the requirements of the European Commission is calculated.

Prediction of the development of the energy poverty issue

The dissertation also includes chapters predicting the possible development of energy poverty. These predictions are calculated on the basis of the models developed and their results based on the current evolution of input values. The purpose of the prediction models is to cover as much as possible the possible scenarios of development, to highlight the pitfalls arising from them and to offer possible directions for solutions. The solutions

proposed should be such that they minimise the hardship for households, reduce energy poverty and at the same time make the most efficient use of the resources spent.

4. Introduction to Energy Poverty Topic

Households are increasingly struggling with fluctuating energy prices, which is leading to instability and rising costs. Energy poverty is now being discussed more often in the Czech Republic. Nevertheless, unlike the most advanced Western European countries, the issue has not been tackled at a high enough level. The biggest shortcomings are the lack of definitions and a detailed description of energy poverty, as well as the lack of strategies aiming to decrease the occurrence and impact of energy poverty on households. Additionally, there is a lack of general awareness of the topic among both professionals and the overall population. Therefore, the first step should be to map out the situation and define specific tasks.

The European Parliament has adopted the EPBD II directive, which sets out basic principles and requirements leading towards a significant decrease in the energy consumption of buildings in the EU. The Czech Republic has to implement the EPBD II in its legislation and create a set of policy measures to achieve final energy consumption savings. Consequently, various support schemes have been introduced that should help households implement savings measures regarding energy losses in their buildings (DG ENER, 2014), (Act No. 406/2000 Coll., 2000), (EED, 2012).

Energy poverty takes two basic forms. The first is unavailability of energy sources, which primarily endangers households in less advanced countries. This form will probably not affect households in the Czech Republic, but Czech households will be endangered by energy poverty caused by a lack of available funding to cover the building's energy demand. In the last few decades, the level of comfort (and consequently energy consumption) in households has increased. The number of appliances has also risen and, generally, a higher quality standard is required than ever before (constant temperature, humidity and other air treatments). To satisfy all these requirements, it is necessary to pay higher energy costs.

It is therefore necessary to establish a definition of energy poverty for the Czech Republic or to adopt a definition used in other Member States that have been dealing with this issue for some time, such as UK (Sovacool, 2015).

Energy poor households are one of the areas where the objective to decrease the final energy demand can be attained. Nevertheless, it is necessary to choose a type of support that will be feasible in terms of the household's income. At the same time, the support must be effective for the shortest payback period possible and for decrease of energy demand. A programme focusing on energy poverty decrease should be based on the requirements of the affected households and should provide sufficient support aiming primarily at decreasing energy expenditures in households while preserving the level of comfort (NAPEE, 2016), (Valentová, 2011).

Households affected by energy poverty cannot invest in savings measures or spend most of their income on energy in order to keep their homes comfortably heated. Therefore, it is desirable to find assistance that would ensure a proper living standard and help decrease energy expenses. Most EU Member States (including the Czech Republic) have not set any anti-energy poverty strategies yet. It is therefore necessary to study and use the knowledge gained by other countries that have been dealing with the issue of energy poverty over a longer period (Waddams Price, 2012), (Bouzarovski, 2012).

The interest of the professional public in this topic is constantly growing. In 2000, 9 professional articles were published, in 2010 already 53 and in 2016 - so far 200 (according to the ScienceDirect database). The SpringerLink database shows the same trend (2000 -1; 2010 -21; 2016 - 50, 2022 – 303 new articles in journals).

At present, there is an uneven level of solutions in individual EU countries. The unevenness is due to differences in national conditions and the time to solve the issue. The most elaborated is probably the issue in GB, where they build on:

The United Kingdom has set out and adopted the Government's strategy to tackle fuel poverty, which focuses on measures to improve the situation, primarily by improving energy efficiency and reducing household fuel costs. This strategy does not include a focus on household incomes as these are part of other policies. In addition, an inter-ministerial group on fuel poverty has been established, with the aim of conducting a strategic review of related policies and initiatives that relate to fuel poverty (GovUK, 2010). Ongoing evaluation is an important part of the strategy to ensure that the right measures are put in place to achieve the objectives as far as possible (GovUK, 2008).

The primary objective of all strategies and policies across countries is to ensure that households can easily provide and maintain heat in their homes. It is part of the policy of the country's leadership to recognize the unacceptable situation in which people cannot achieve the kind of heat that would ensure a healthy and comfortable environment (GovUK, 2015).

The issue of energy poverty is also addressed by the European Commission, and to address this issue, the Energy Poverty Advisory Hub (EPAH) was established. The aim of this project is to ensure access to energy services and products while also empowering European citizens. EPAH serves as an advisory centre for energy poverty and is a leading EU initiative with the goal of eradicating energy poverty and ensuring an accelerated and fair energy transformation (EPAH, 2021).

As part of EPAH, there is a series of reports prepared for each country, providing a basic overview of the situation, estimates of the number of households affected by energy poverty, and relevant resources. The report for the Czech Republic also includes a link to

the published article "Programme to reduce energy poverty in the Czech Republic," which presents the initial results of estimating the number of households affected by energy poverty as part of the work on this doctoral thesis (EPO, 2020).

The issue of energy poverty is related to the topic of energy efficiency in buildings, which is connected to international efforts to address climate change issues on Earth. The European Union has set its goals and aims to achieve them through legislation and subsidy programs. It is important that households affected by energy poverty have access to these tools and are not prevented from using them to improve their situation due to their current circumstances. Therefore, it is necessary to monitor European legislation and directives.

In 2002, the European Parliament and Council issued Directive 2002/91/EC on the energy performance of buildings (EPBD) on December 16, 2002. This directive primarily deals with the energy efficiency of buildings, but it also extends to the issue of energy poverty. More detailed analysis of the directive will be provided in the following chapters. The directive has been updated twice (EPBD II in 2010 and EPBD III in 2018). The updated versions of the document now delve more deeply into the issue of energy poverty (EPBD, 2018).

Based on the requirement of the Directive 2012/27/EU of the European Parliament and the Council on Energy Efficiency (EED), the member states of the Union are obliged to submit national energy efficiency action plans every three years. The first document of the National Energy Efficiency Action Plan was created for the Czech Republic in 2007. These documents are regularly updated and evaluated after a few years. The directive was updated in 2018 and 2023 (MIT, 2018).

The issue of energy poverty is also addressed by the concept of social housing in the Czech Republic. Social housing aims to provide affordable and suitable housing for individuals and families with low incomes. Incorporating energy-efficient measures into social housing can help reduce energy costs and improve living conditions for these tenants. The Ministry of Labor and Social Affairs was entrusted with the proposal of a conceptual solution to the issue of social housing in the Czech Republic by Resolution No. 153 of the Government of the Czech Republic on March 12, 2014. The concept is continuously evaluated and supplemented with current data, ongoing analyses are conducted, and their results are presented (MLSA, 2021).

In order to set the right strategies and decrease energy poverty, this issue has to be precisely defined. As the Czech legislation, has not drawn up its own definition yet or adopted a definition from other countries, the definition of the European Commission is most often used. However, this definition is rather vague. Another option is to use the more accurate definition of Great Britain:

A household is in fuel poverty if, in order to maintain a satisfactory heating regime, it would be required to spend more than 10% of its income on all household fuel use (Moore, 2012), (GovScot, 2006).

The definition is clear and comprehensible and shows the exact energy poverty threshold. Yet, before this definition is adopted by other countries, it should be considered whether the definition and its parameters correspond to the parameters of the given country (e.g. the Czech Republic) and whether the definition is applicable there. Each country should consider local conditions and customs, particularly lifestyle and comfort requirements, when setting the definition of energy poverty.

Energy poverty is becoming an increasingly significant and pressing issue in today's society. This phenomenon, which has serious social and economic implications, occurs in many countries worldwide, including the Czech Republic. Energy poverty refers to the situation where households lack sufficient financial resources to meet their basic energy needs. This inadequacy hinders their access to a safe, reliable, and affordable energy source, which is essential for fulfilling basic necessities such as heating, lighting, and cooking.

Energy poverty represents a significant issue that affects various groups of the population, including seniors, low-income families, unemployed individuals, and people living in substandard housing. These individuals often find themselves trapped in a cycle where high energy costs consume a substantial portion of their incomes, limiting their ability to invest in improving the energy efficiency of their homes or utilizing renewable energy sources.

As a result of energy poverty, affected households face negative consequences for their health and well-being. These include inadequate heating conditions, increased risks of illnesses related to cold or overheating, and restricted access to basic social and economic opportunities. Furthermore, energy poverty has a detrimental impact on the environment, as households compelled to rely on inefficient energy sources contribute to increased greenhouse gas emissions and negatively affect air quality.

To effectively address the issue of energy poverty, it is essential to develop strategies and policies aimed at reducing its occurrence and mitigating its negative impacts. This encompasses improving the energy efficiency of buildings, providing financial assistance to vulnerable households, fostering the development of social housing, and raising awareness about energy poverty within society.

4.1 Energy efficiency of the building

In modern construction sector, there is an effort to achieve the lowest level of energy consumed during the building construction and its usage. Improvement of energy efficiency is achieved by adopting a more efficient technology or effectiveness of production process,

or by using generally accepted methods to reduce energy losses. Energy consumption has grown rapidly over recent decades. From the economic point of view, it is important to set energy efficiency that is more valuable than investment resources. Fossil fuel resources are decreasing, and their prices are rising.

Another important factor is the energy consumption and its costs during the operation of a building. A satisfactory level of operating costs has to be achieved. An ecological view is equally important. Higher energy demand means greater environmental burden. It is necessary to reduce carbon emissions released into the atmosphere and save natural resources such as oil, coal and gas. If energy is used as little as possible in all stages of a building life, buildings will be less dependent on energy sources.

It may seem that the more substantial energy efficiency measures are carried out the more energy is saved, but this point of view takes into account only the final energy consumption (FEC). Therefore, choosing measures resulting in a building whose comfort has been improved and which is rather independent of fuel consumption is far more important, as well as providing measures which ensure low primary energy consumption from non-renewable sources.

The price of such energy efficiency measures remains the key factor; other important factors are fuel costs and non-energy benefits. A decision related to a single building is made on the basis of tenders submitted. In the case of projects on the national or EU level, decisions are made on the basis of databases which are not sufficient and complete. In order to make the right decision, it is necessary to create a new tool to visualize data regarding the cost amount and payback period, adding data into statistical tools (Eurostat, 2019), or broadening the range of tool focusing on energy efficiency measures as well as on mapping of a building´s data (ENTRANZE, 2014), (TABULA, 2016)

The Member States have committed themselves to meet the requirements involving the calculations of the cost-optimal level of minimum energy performance requirements by using a comparative methodology framework elaborated in compliance with article 1 of Directive 2010/31/EU of the European Parliament and of the Council on energy performance of buildings, including relevant parameters such as climatic conditions and practical accessibility of energy infrastructure. The results of this calculation shall be compared to the minimum energy performance requirements in force (EPBD, 2010), (BPIE, 2014).

The Member States shall report all input data and assumptions used for these calculations as well as all calculation results. The report may be included in the Energy Efficiency Action Plans referred to in Article 14 (2) of Directive 2006/32/EC. The Member States shall submit the reports to the Commission at regular intervals, which shall not be longer than four

years. Following the requirements, the first report was submitted on 30 June 2012 (ECOFYS, 2014), (EC(a), EC(b), 2016).

4.1.1 Czech legislation related to the energy poverty issue

In the Czech environment, the issue of energy poverty is addressed by documents at the legislative level through:

Act No. 406/2000 Coll. on energy management, this document is the key law in the field of energy use in the Czech Republic, which includes measures to increase energy efficiency and responsible energy management. It also sets rules for the establishment and creation of the State Energy Concept, which should be in line with the addressed issues to ensure that its objectives correspond to the goals for addressing energy poverty.

To gain a better understanding of the energy poverty situation in the Czech Republic, it is necessary to gather available data on households. The easiest and most accurate data available comes from statistical sources, such as population and housing statistics from the Czech Statistical Office. While the information obtained from these sources may not be detailed enough to directly identify households affected by energy poverty, it will suffice to gain an overall overview of this issue.

Decree No. 264/2020 Coll. Decree on the energy performance of buildings, this document incorporates European Union regulations and sets out cost-optimal requirements for the energy performance of new buildings and major renovations of existing buildings. It also outlines the method for calculating the energy performance of a building and provides a template for determining recommended measures to reduce a building's energy demand. These requirements should be considered when designing measures to alleviate energy poverty, ensuring their alignment with this decree.

The energy sector is undergoing changes and must adapt to new trends such as decarbonization and energy decentralization. Developments in this field also impact the issue of energy poverty, potentially offering new solutions or defining its limits. The fundamental legal document is **Act No. 458/2000 Coll., on the Conditions of Business and the Exercise of State Administration in the Energy Sectors and on the Amendment of Certain Laws** (Act No. 458/2000 Coll.).

4.1.2 European legislation related to the energy poverty issue

The legislation of the European Union is an integral part of the legal order of each Member State. The European Commission (EC) has established an initiative on new legislative proposals. It is important to monitor the EC work programs in order to know its priorities for upcoming years. Then the Member States can adopt the EU legislation and adjust it to

their national conditions. The following text summarizes important legislative documents that have significant influence on the development of energy efficiency for the European Union and for each Member State.

Clean Energy for All Europeans & Renovation Wave packages

In November 2016, the European Commission introduced a set of measures aimed at preserving the European Union's competitiveness, given the ongoing global energy market shift towards clean energy. The target is to achieve a minimum 40% reduction in CO2 emissions by 2030. (EC(a), 2016), (EC(b), 2021)

The package establishes two key EU targets for 2030: The initial target is a minimum of 32% renewable energy usage, and the second objective is a minimum energy efficiency improvement of 32.5%. These benchmarks will be implemented in 2023, with the possibility of reassessment for potential increases. These goals are intended to enhance Europe's competitiveness, create more job opportunities, lower energy costs, address issues related to fuel poverty, and enhance air quality.

The package includes 8 different legislative proposals:

- Energy Performance in Buildings;
- Renewable Energy;
- Energy Efficiency;
- Governance;
- Risk-Preparedness Regulation;
- Electricity Market Design;
    - Electricity Regulation;
    - Electricity Directive;
- Rules for the ACER regulator.

The main goals for Clean Energy for All Europeans package are:

- Putting energy efficiency first;
- Achieving global leadership in renewable energies;
- Providing a fair deal for consumers. (EC(b), EC(c), EC(d), 2016).

In 2020, the Renovation Wave strategy and action plan were officially published. This publication was accompanied by a comprehensive document that presented a range of EU funding solutions available to support the Renovation Wave. These funding options were designed to offer diverse avenues of financial assistance to facilitate the initiative's goals.

The Renovation Wave initiative outlines three primary focus areas for its efforts. First and foremost, it aims to address the issues of energy poverty and the rehabilitation of the worst-performing buildings. Secondly, the initiative places a significant emphasis on the

renovation of public buildings and essential social infrastructure. Lastly, a key objective is the decarbonization of heating and cooling systems. (EC, 2020)

Directive (EU) 2018/844 on the energy performance of buildings

The Directive (EU) 2018/844 of the European Parliament and of the Council, amending Directive 2010/31/EU on the energy performance of buildings and Directive 2012/27/EU on energy efficiency, represents one of the most pivotal documents issued by the European Parliament concerning energy efficiency. This directive was published on May 30, 2018. Member States are mandated to incorporate the directive's requirements into their legislation by March 10, 2020. Furthermore, there has been a modification to the original limit for greenhouse gas emissions, with a new target demanding a 40% reduction (compared to 1990 levels) by 2030. Additionally, there is a concerted effort to establish a competitive and decarbonized energy system within the European Union.

The directive focuses also on existing buildings whose energy consumption should be reduced. It is recommended to renovate these buildings according to nZEB standards; every year 3% of the existing housing stock should be renovated. This strategy would help to reduce dependency on energy imports.

The directive also tackles the issue of energy poverty, recognizing the necessity to address it based on established criteria. Member States are required to compile an overview of policies and measures within their long-term renovation strategies aimed at facilitating the renovation of both residential and non-residential buildings at the national level. Furthermore, Member States are obligated to furnish an overview of pertinent national initiatives contributing to the mitigation of energy poverty. (EPBD, 2018)

The Article 4 is one of the most important parts of this directive. By adopting this document, Member States are committed to take measures that are necessary to ensure minimum requirements for the energy efficiency of buildings. These measures should be such as to achieve cost-optimal levels (EPBD, 2010).

Article 4 Establishment of minimum energy performance requirements

Member States shall take the following measures:

- To ensure that minimum energy performance requirements for buildings or building units are set with a view to achieving cost-optimal levels;
- To ensure that minimum energy performance requirements are set for building elements that form part of the building envelope and that have a significant impact on the energy performance of the building envelope when they are replaced or retrofitted, with a view to achieving cost-optimal levels;

Energy performance of building

Energy performance of a building must be expressed as a numerical indicator of primary energy consumption in kWh/(m^2.year) for the purposes of energy performance certification and compliance with minimum energy performance requirements. The methodology to determine energy performance of a building must be transparent and open to innovations.

Energy Performance Certificate (EPC)

EPC is integral part of the Energy Performance of Building Directive (EPBD). The document carries information on the energy performance of a building's operation. The document serves to evaluate the energy performance of a building, qualifies the energy consumed by using the building and puts it in the right category. The certificate is part of an energy audit.

The EPBD recast provides Member States with a guidance on the EPC calculation methodology in line with EU standards. Member States can modify the calculation procedure and requirements, but they have to meet European requirements. Annex I of the EPBD states that energy performance of buildings can be assessed on the basis of a calculated (known as asset rating) or actual (known as an operating rating) energy consumption. At the same time, it must reflect the energy needs associated with the given type of use. Out of the 28 countries of the European Union, 14 countries have adopted a methodology based on calculated energy consumption. Calculated consumption is based on the building model which corresponds to the future features of the building design or to an existing building. In the rest of the EU countries, both actual and calculated energy consumption is expected to depend mainly on the type or age of the building (BPIE, 2014).

ISO 50001 – Energy management

The document ISO 50001 is a new international standard which sets the requirements for the implementation and certification of the energy management system. ISO 50001 is based on the Continuous Management Improvement Model, also used for other standards such as ISO 9001 or ISO 14001. This makes it easier for organizations to integrate energy management into overall efforts to improve quality and environmental management. The document describes all energy management requirements during all stages (establishment, implementation, maintenance and optimization). It addresses all phases of implementation and operation of the energy management system of organizations of any size or focus. The standard provides guidance and advice on benchmarking, measuring, documenting, setting energy efficiency improvements, and the planned reduction of greenhouse gas emissions (ISO 50001, 2018).

The objective of implementing this standard is to attain energy savings. These energy savings are realized through comprehensive measures that impact overall consumption, including:

- Introduction of systematic evidence of meters, appliances and their consumption;
- Performing consumer analyses;
- Determination of energy consumption plan;
- Evaluation of accidental and unexpected energy consumption;
- Training of responsible persons, allocation of first-level and accountability;
- Performing revisions of energy performance indicators;
- A list of possible opportunities to improve energy performance.

The standard outlines a straightforward principle for formulating energy policy plans and objectives. These plans are executed through established procedures, and their efficiency is assessed, quantified, and tracked. Based on the established data, proactive measures must be taken to attain the established goals. The standard operates on the basic PDCA (Plan-Do-Check-Act) framework:

Determination of energy policy → Planning → Implementation of operation → Control → Evaluation

The areas in which implementation of ISO 50001 can improve:

- Increase of the energy efficiency of a building;
- Reduction of the energy costs of a building;
- Contribution to the increase of energy security.

It is necessary to ensure the synergy/cooperation of legislative documents relating to this issue. New grant programs proposed for increasing the energy efficiency and reducing energy poverty must build on the current legislation. The coherence of legislative documents shall ensure efficiency of the process.

Directive on energy efficiency and amending Regulation (EU) 2023/955

By adopting the Energy Efficiency Directive, European states committed to reducing energy consumption in buildings. The directive and its amendments encompass various areas in the field of energy management, including goals and measures for their fulfilment. Among other things, the directive introduces the obligation of proportionate heat and hot water metering and the allocation of costs to final consumers. In late March 2023, the European Parliament and the European Council agreed on a target for 2030. The goal is to reduce energy consumption by 11.7% compared to energy consumption forecasts for 2030. After the adoption of this legislation, the Czech Republic, like other EU countries, will have to

achieve an average annual savings of 1.49% of final energy consumption (compared to the existing target of 0.8%). The principle of "Energy Efficiency First" has been legislatively established, requiring energy efficiency to be considered in planning, decision-making, and major investments not only in the energy sector but also beyond it. The directive also introduces energy communities and their influence and implementation under the "Energy Efficiency First" principle.

4.2 Supporting schemes and other policies

Grant programs allow households to benefit from support schemes and financial resources. This use depends on the implementation of austerity measures or other conditions. This principle helps achieve the targets for energy savings. The following text shows one of the grant programs.

Czech Republic policies

Subsidy programs in the Czech Republic can be divided according to the target group on which they focus. There are two basic areas of focus, namely households and businesses. The following text lists the main subsidy programs and their impact on energy efficiency.

- The new green savings programme - The main objective of this programme is to reduce energy consumption of existing buildings and encourage the construction of new buildings with very low energy consumption and efficient use of energy resources. The programme contributes to improving the environment by reducing greenhouse gas emissions. The programme is managed by the State Environmental Fund of the Czech Republic. (MoE(a), 2018)
- “EFEKT” programme – Programme of the Ministry of Industry and Trade which supports the realization of energy savings in public lighting, retrofitting the heating system, energy management, education, promotion and pilot projects. Subsidies from EFEKT may be provided to different entities, the admissible type of applicant is specified for individual activities. (MIT, 2017)
- “Panel 2013+” programme - The programme provides low-interest loans for repairs and modernization of apartment buildings. The programme focuses on complex repairs, so the owners spend their money efficiently. The loan is provided up to a maximum of 90% of the eligible expenditure. (MoE(b), 2018)
- Operational Programme Environment - The programme focuses on public buildings. It increases the use of renewable energy sources, reduces energy intensity and demands achieving high energy standards for new public buildings. (SFRB, 2018), (SFPI, 2022)

Support programs in the Czech Republic appropriately emphasize the enhancement of energy efficiency, encompassing a wide range of building types. However, from the end-users' perspective, there seems to be a gap in programs aimed at raising awareness about energy efficiency issues and guiding households and businesses in making informed, cost-effective choices tailored to their specific building and usage needs. Introducing such a programme would be a valuable addition to the existing ones.

One significant drawback of grant programs in the Czech Republic is the absence of initiatives targeting low-income households or those grappling with energy poverty. The 2013+ programme offers low-interest loans, and adopting a similar approach for single-family homes, along with expanding the New Green Savings program, could extend support to a larger number of households.

4.3 Policy impacts on energy-poor households

In 2022, the document "Study on the impacts of policies to decarbonize residential buildings on energy poverty in CEE/SEE and mitigation strategies" was created. This document focuses on assessing the impacts of selected implemented policies on low-income households in EU countries. The document identifies low-income household groups in individual countries for which model scenarios were developed. The obtained data and the modelling itself were verified by national expert teams. The author of this dissertation was part of the Czech expert team.

- *Baseline scenario – This base scenario assumes the continuation of the current trajectory without the implementation of additional policies. The scenario includes the consideration of energy price increases, which were set based on the reference scenario for the EU until 2020.*
- *Scenario 1 - The foreseen increases of energy prices within the framework of the EU Reference Scenario 2020 were taken into account in additional to the increase due to the carbon pricing. Scenario 1 was selected for the projection of the electricity price.*
- *Scenario 2 - Mandatory phase-out of heating oil and solid fossil fuels in 2030 and natural gas (including LNG) in 2040. It was considered that the actual phase-out will have occurred after five years (heating oil and solid fossil fuels in 2035 and natural gas and LNG in 2045), and heat pumps will replace the existing heating systems. The installation cost of the heat pumps was assumed equal to €8,000.*
- *Scenario 3 - Establishment of MEPS for achieving energy class E in 2035. 50% of the affected households (75% of the total low-income households) will renovate their buildings until 2030 and remaining buildings until 2035. Assumptions for buildings' energy upgrade: Renovation cost: €10,000/dwelling and delivered final energy*

savings: 30%. In 2040 all the building will be upgraded to energy class D (Assumptions for buildings' energy upgrade: Renovation cost: €5,000/dwelling and delivered final energy savings: 10%). It should be noted that the renovation costs for the case of Hungary was assumed to be slightly higher (€13,500/dwelling and €6,500/dwelling in 2035 and 2040 respectively).

- *Scenario 4 - Scenario 4 represents a combination of measures and developments characterizing scenarios 2 and 3.*
- *Scenario 5 - Scenario 5 represents a combination of measures and developments characterizing scenarios 1, 2, and 3* (IEECP 2022).

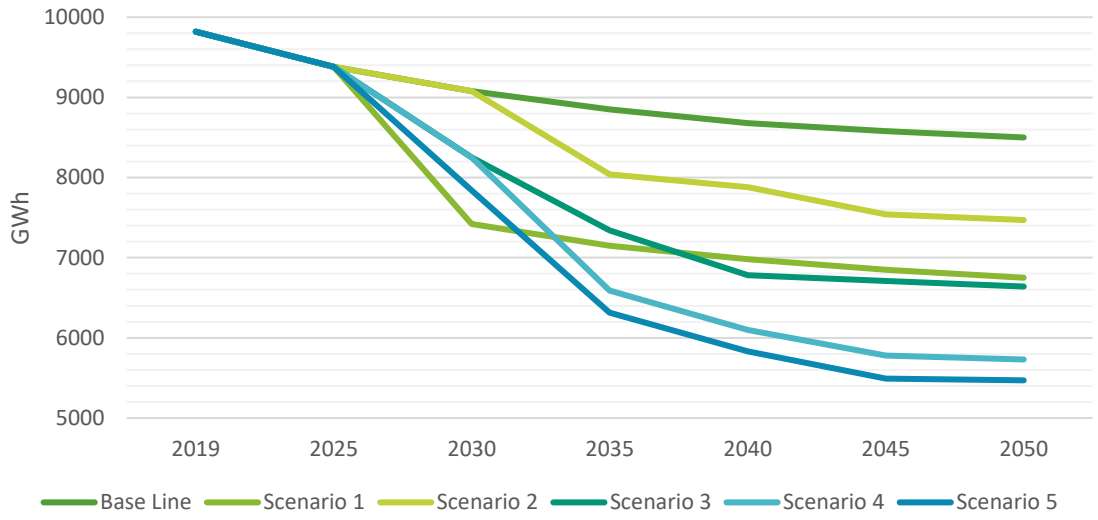


Figure 1 - Comparison of final energy consumption between scenarios in Czech Republic

Source: Study on the impacts of policies to decarbonize residential buildings on energy poverty in CEE/SEE and mitigation strategies; Model - IEECP 2022, national data - author

The scenarios illustrate the impacts on energy consumption based on the support for energy measures in low-income households. It is evident that compared to the baseline scenario, a significant reduction in final energy consumption is achieved.

Table 1 - Investments in different scenarios in Czech Republic

		Year					
	Investments (million €)	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Scenario 2	Heat pumps	0	0	1,079	0	1,315	0
Scenario 3	Building envelope	0	3,340	3,340	3,340	0	0
Scenario 4	Heat pumps	0	0	1,079	0	1,343	0
	Building envelope	0	3,340	3,340	3,340	0	0
	Total	0	3,340			1,343	0
Scenario 5	Heat pumps	0				1,221	0
	Building envelope	0	3,340	3,340	3,340	0	0
	Total	0	3,340			1,221	0

Source: Model - IEECP 2022

The scenarios envisage the commencement of investments in energy-saving measures starting from 2035. The primary allocation of funds is directed towards renovating building thermal envelopes, and in accordance with specific scenarios, modern technologies are supplemented as well, with a particular focus on heat pumps as a heating source.

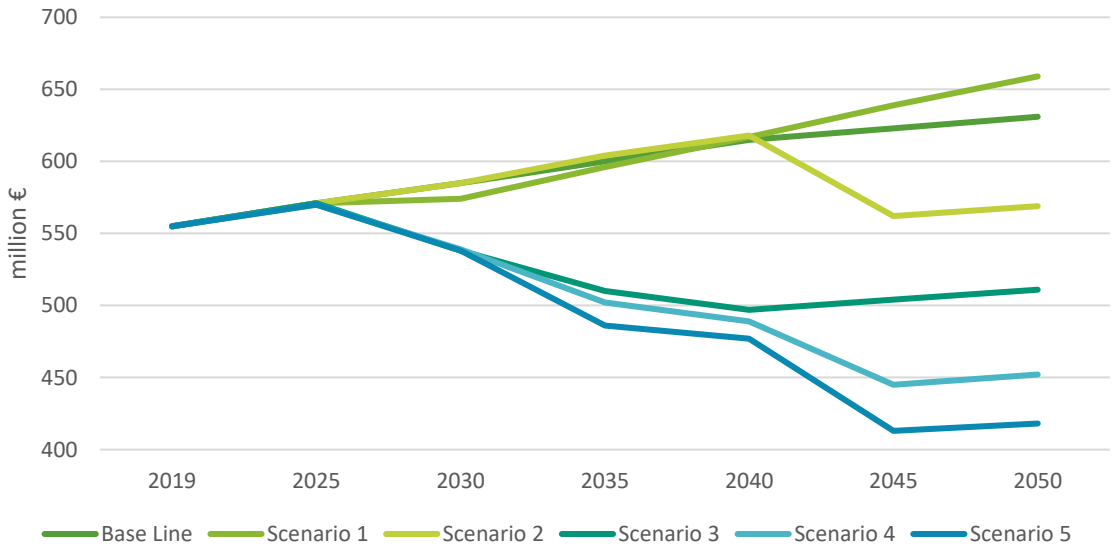


Figure 2 - Comparison of final costs between scenarios in Czech Republic

Source: Study on the impacts of policies to decarbonize residential buildings on energy poverty in CEE/SEE and mitigation strategies; Model - IEECP 2022, national data - author

The energy costs for low-income groups in all countries which ban new fossil fuel boilers do not seem to change substantially and neither for the ETS2 as a standalone measure.

The greatest financial savings are brought about by a combination of measures presented as Scenario 4 and Scenario 5. Compared to the baseline scenario, it's possible to achieve up to a 35% reduction in final costs.

Through the combination of measures, the relative energy costs (in comparison to the baseline) remain constant or decrease over time as a result of the combination of lower energy consumption and higher energy prices for these policy scenarios. However, it must be taken into consideration that this assumption is rather conservative for low-income households. The conclusion comes from the research on the specific price elasticities of low-income households (IEECP 2022).

4.4 Protection of vulnerable customers

The state should help protect consumers if there is a singular and unexpected downtime and the household is not able to pay for energy. Legislation should protect consumers but, at the same time, should be protected against abuse. The most frequent protection is in the form of energy supply, so the customer is not disconnected immediately upon non-payment.

Each EU state defines the term "vulnerable customer" differently and has a different approach to protecting people who fall under the definition of this term. Some EU countries that have different approaches are selected in the following text.

> *Belgium: Vulnerable consumers can be entitled to certain benefits that help them to pay their energy bills. Depending on the exact nature of the benefit (e.g. access to a social energy tariff, free energy scan, social renting tariffs for energy saving, etc.), different welfare system parameters are used to specify eligible customers. (ESPN, 2020)*

> *Croatia: Vulnerable consumers are recipients of social welfare and include people with disabilities, who are eligible for a monthly deduction in their electricity bills of about 26 Euros per month independently of the amount of their bills. (Robić & Rogulj, 2021)*

Many other countries within the European Union have anchored the protection of vulnerable customers in their welfare system and legislation.

Case study: Protection of consumers in arrears with electricity bills in the Czech Republic

Consumer protection in the Czech Republic is addressed within the Energy Act, which outlines the circumstances under which a customer can be disconnected from their electricity or gas supply. The upcoming studies will delve into the legal text and its application within the operational framework of energy suppliers.

The transmission system operator retains the authority to restrict or suspend electricity supply to participants in the electricity market in the event of an unauthorized takeover.

An unauthorized takeover refers to recurrent failure to meet agreed-upon payment obligations or obligations stemming from compensation for damages incurred due to unauthorized electricity consumption, even after prior notification (Act No. 458/2000 Coll.).

In accordance with the law, an electricity supplier has the right to disconnect a customer if they fail to pay the electricity deposit twice consecutively or neglect to pay a deposit after being duly notified by the supplier. The risk of disconnection primarily affects households struggling with punctual payment of their electricity deposits. Should they fall behind in payment twice in succession, these households may face disconnection.

Suppliers' reaction to the current wording of the law may slightly differ, yet their approach is similar:

- ČEZ supplier - CEZ Electricity Supply Company may withdraw when the customer commits an unauthorized takeover, in particular in the case of repeated non - compliance with the agreed payment obligations, which are not fulfilled even after a written notice. Upon any failure to pay in due time, we are authorized to charge you a fee of 240 CZK. (ČEZ, 2018);
- Bohemia Energy Supplier - Termination of the contract and interruption of electricity supply: The supplier is entitled to withdraw from the contract if the customer has breached the contractual terms. Any repeated non-fulfilment of the contractual payment obligations on the side of the customer shall be considered a breach of the contractual terms. (payment of advances, invoices, ...) (BE, 2018)
- Comfort Energy Supplier - Supplier is entitled to withdraw from the Contract and terminate supply in the event of substantial breach of contractual obligations by the Customer. Significant breach of contractual obligations occurs upon repeated failure to comply with the contractual payment obligations (i.e. any advance payment, invoices for combined services of the delivery of commodity, etc.) (CE, 2018).

The same protection of the consumer against disconnection from the power supply is anchored in the Czech law to protect the consumer.

4.5 Programmes for reducing energy consumption in the Czech Republic

To achieve the objectives pursued in the field of final energy consumption savings, the Czech Republic has undertaken subsidy schemes. These schemes are aimed at households struggling with substantial energy loss (heat losses through the building envelope, heat losses in production, heat distribution and heat losses in lighting systems).

The focus of these programmes is almost identical to that of the programmes for reducing energy poverty, but households affected by energy poverty do not have sufficient financial means to invest. The subsidies are paid retroactively, so that the households have to cover the expenses themselves. As low-income households cannot save funds needed to cover the expenses, a loan is their only option. However, energy poor households often have difficulty obtaining a loan, as the lender deems them insolvent (Karásek, 2016).

Therefore, the subsidy scheme to reduce energy poverty in the Czech Republic should retain the same focus while changing the way in which subsidies are paid.

Another major issue is the programme in relation to the type of housing. A household living in its own house will have different requirements than a household living in an apartment building. Austerity measures designed for an apartment building take into consideration the types and financial possibilities of households. The Panel 2013+ programme has a very positive attitude towards the issue of energy poverty, providing a low interest loan to finance the refurbishment and renovation of houses (SFRB, 2016), (SEF, 2016).

New Green Savings Light

In 2023, a new subsidy programme for energy savings was launched. This programme is the most suitable among the existing subsidy programs to address the needs of reducing energy poverty in the Czech Republic. The program's objective is to reduce energy expenses for low-income households.

The programme focuses on:

- Insulating the building's perimeter structures;
- Replacing windows and entrance doors;
- Installing thermal or photovoltaic systems for water heating.

The program's conditions for obtaining funds are strictly limited and set to primarily benefit low-income households and retiree households. Financial resources can be obtained in advance after filling out an application, but their amount is very limited. For instance, in the case of facade insulation, financial resources are capped at CZK 150,000 (CZK 6,000 per running meter). To cover all or at least significant expenses for facade renovation, the building must be small. From this perspective, the program's focus is set correctly, but the financial assistance for energy-poor households can be utilized by only a small portion of these households. Nonetheless, it is a step in the right direction towards reducing energy poverty in the Czech Republic.

The most suitable use of the New Green Savings Light programme is for the replacement of opening structures. For this purpose, the programme is highly suitable and can bring significant energy savings, especially for older, less energy-efficient buildings. However,

window replacement can also have negative consequences. Proper ventilation of the building must be ensured during window replacement. New windows can be tighter than the old ones, which can restrict natural airflow. This can lead to the accumulation of harmful substances and moisture. In older buildings, mechanical ventilation is often not installed. Therefore, along with window installation, a change in behaviour by occupants who will need to ventilate more frequently and correctly will be necessary. If building renovation is not carried out comprehensively, partial renovations can lead to new negative effects.

The trend that should be encouraged is comprehensive building renovation, where the building is renovated to the greatest extent possible, ensuring compatibility among all elements and structures in the building's operation. This results in a highly modern building with energy-efficient operation and low energy consumption.

4.6 Social Housing Programmes

Although the Czech Republic does not provide any support schemes focusing on tackling energy poverty, there are programmes which could have a positive influence on its reduction. One of the main factors causing energy poverty is low household income. The state system of social benefits operates with a level of 30% (35% for Prague) of total income spent on housing costs. Individuals and families who fall in this category are entitled to state housing benefits. If the benefits are not sufficient and individuals or families are in a difficult economic situation which they cannot remedy, they can use the option of social housing (MLSA, 2015).

Since 2003, the Czech Republic has granted subsides aimed at housing construction for people with low income. There is no entitlement to such a flat, because they are rented on the basis of a contractual relationship between two entities. Communities should preferably enter into lease contracts with low income earners who spend more than 40% of their income on housing (MoRD, 2016).

According to the above-mentioned definition, people who fall in this group belong to the energy poverty group as well. Although the social housing programme helps resolve the energy issues of individual families, who can move to more affordable flats, the issue of energy inefficient buildings remains unresolved. New occupants of the building will have to pay high energy costs without achieving a decrease of energy demand, which is highly desirable when trying to reduce energy poverty.

4.7 Law on Aid for Citizens in Need

The system of support which is paid according to the Law on Aid for Citizens in Need is focused on situation when the citizen cannot help themselves from a poverty. The support is allocated in several branches:

- Subsidy on cost of living;
- Subsidy on housing costs;
- immediate emergency relief aid.

According to the official definition, a person is in material need when his or her income after a deduction of adequate cost for housing is lower than a minimum value of cost for living. Renting a flat, regular cost for maintenance of the flat and energy cost is considered as adequate cost for lining. The costs are limited up to 30% of the income, in city of Prague 35%.

The national aid for citizens in need covers also households affected by energy poverty. The current approach, however, does not solve the cause itself. The energy efficiency improvement of the building cannot be financed within this support (MLSA, 2011).

4.8 Assistance in Material Need

The Czech Republic has a system of assistance for people in material need. This assistance is ensured by a system of benefits, which is regulated by Act No. 111/2006 Coll., on aid in material distress, Act No. 110/2006 Coll., on the minimum subsistence level and Decree No. 389/2011 Coll., on the implementation of certain provisions of the Act on aid in material distress.

The basic purpose of this system is to help people who do not have sufficient income and to help them meet their living needs. The system can help with the following benefits:

- Housing allowance;
- Supplementary housing allowance;
- Emergency immediate assistance.

In the context of fuel poverty, the most interesting is the second aid option - the housing benefit. If a person's or household's income is not sufficient to cover housing costs, it is possible to draw a housing allowance from the state social support system. (MLSA, 2011)

Table 2 - Expenditure on aid benefits - comparison between January 2022 and January 2023

	Number of paid benefits (in thousands)		Retrieved from in the month (CZK million)	
	January 2022	**January 2023**	**January 2022**	**January 2023**
Material assistance benefits in need:				
Housing supplement	31.3	31.8	136.0	154.0
State social assistance benefits:				
Housing allowance	143.2	229.9	540.7	1,125.9

Source: (MLSA, 2023)

The data indicates a significant rise in disbursed benefits as well as the amount provided through them. The increase in housing assistance between 2022 and 2023 has soared by up to 208%. This surge is primarily attributed to the instability in the energy market, where there has been a substantial increase in energy prices for households. Based on this data, it can be concluded that households in the Czech Republic are highly susceptible to price increases, which can be partially mitigated by the social system, but for a more sustainable solution, it is advisable to explore alternative forms of assistance.

In order to be eligible for a housing allowance, you must be eligible for a livelihood allowance. From a household perspective, this system is very useful if the household finds itself in a situation where it cannot manage its housing costs. If a household's costs are high due to energy poverty, it is necessary to be vigilant and address the issue through other means. The housing allowance ensures a short-term income gap but is not a long-term solution. Energy poverty requires a more comprehensive solution aimed not only at ensuring sufficient funds to cover household expenses but, above all, a system that will achieve a long-term reduction in housing costs, eliminating the need for social benefits and achieving lower housing and energy costs. This can be achieved by ensuring the energy efficiency of buildings or increasing self-sufficiency in energy production.

5. Methods used

This chapter describes the methods and procedures used in the doctoral thesis. It outlines the data collection process, which involved the analysis of statistical data on household incomes, building characteristics, and energy consumption. Additionally, it introduces the fundamental principles for employing mathematical models and the approaches used for calculations utilized in the thesis, including estimating the number of energy-poor households and calculating energy savings within these households.

5.1 Selection of energy poverty indicators

It is necessary to establish indicators that show at least two levels of energy poverty. The first level should consider the results at the national level. Therefore, to compare the situation in various European and other countries a unified system should be taken into account for determining energy poverty. Studies and their results should be independent of local requirements and should consider mainly data showing satisfaction of the requirements. These results will not reflect the cause of energy poverty, but it will be possible to assess them according to the percentage of energy poor households and to compare them with the results in other countries.

The national level should also indicate endangered households in relation to local conditions and should help identify the cause of energy poverty. Then the best practices to decrease energy poverty can be set. The issue of energy poverty is influenced mainly by the development of energy prices, energy consumption in households and household income. These are the main factors that help track the development of energy poverty in the country. To learn about the risks of energy poverty, it is essential to know the data pertaining to particular households, as these may differ in relation to the type of building as well as to its technical condition, which largely influence energy consumption (Rademaekers el. al., 2016).

Indicators must be divided according to the types of data examined. Indicators needed for comparing the situation in various countries differ from those showing conditions in particular countries or for examining particular projects. The first group involves indicators based on household income and expenses data. One of the most frequently used indicators in Europe is the Ten Percent Rule, which is an essential condition of the British definition of energy poverty. The line is determined by household income and expenses, but the rule does not consider the heat and technical condition of the building, which is (indirectly) included in household energy expenses. Therefore, the rule can be understood as an indicator of household conditions, but it is not able to identify the cause of energy poverty (Taylor, 1993).

Another possible indicator is Low Income High Costs (LIHC), which can be used for cross-country comparison as well. This indicator can identify energy poor households and at the same time shows the difference between household energy expenses and the energy expenses median of all households (Hills, 2012).

Indicators reflecting the situation at the national level must also provide information concerning local conditions in particular regions. Most importantly, they should reflect information regarding energy prices, median household income, the state of the housing stock and the climatic zones.

The last important group of indicators are indicators of energy poverty in relation to particular projects. In addition to showing the financial situation of households, these indicators should mainly determine the potential causes of energy poverty so that the impact of energy poverty can be eliminated or reduced to an acceptable level.

5.2 Comparative Analysis

An analysis of approaches and data was conducted, enabling a comparison of energy poverty among different countries and regions. Based on the acquired data, various approaches to addressing the issue of energy poverty in different countries worldwide were identified. The impacts of energy poverty and its overall form, as well as its influence on household livelihoods, were compared. By comparing approaches and their applicability to the Czech Republic, measures were proposed that could assist in addressing energy poverty in the country.

5.3 Quantitative Method

The method of collecting and examining statistical data was employed. Data will be collected from publications and public databases of official institutions (primarily including data from the Czech Statistical Office and Eurostat). The use of statistical analyses and quantitative methods can be highly useful in investigating energy poverty. These methods allow for systematic data collection, analysis of relationships, and identification of trends, leading to a deeper understanding of the causes and impacts of energy poverty.

Statistical models were utilized for predicting the future development of energy poverty and key factors influencing it. Predictions were formulated based on current trends and variables. The statistical data and resulting predictions served as the foundation for modelling.

5.4 Modelling of households and energy consumption

Modelling methodology was employed within this work. The characterization of energy poverty in Czech households was modelled, primarily focusing on determining the number of households affected by energy poverty. As comprehensive data describing the current situation, considering combinations of household situations, energy prices, and housing conditions, were unavailable, two models were created.

The first model, based on the distribution of household incomes and the percentage probability of household and housing group categories, provides a simple estimate of the prevalence of energy-poor households in the Czech Republic. This deterministic model utilizes fixed data from the Czech Statistical Office database.

The second model employs stochastic modelling principles. Based on identified statistical data, the probabilities of specific household characteristics were determined. Subsequently, the model generates counts of households characterizing the Czech Republic. The model operates using a collection of generated datasets, allowing for the incorporation of variations in model outcomes.

5.5 The use of statistical data in model

When looking for the optimal way to approach the issue of energy poverty, we must consider the systems applied in EU countries. Foremost among them is the system in Great Britain. However, in order to adopt and correctly implement programmes focusing on energy poverty, it is necessary to find similarities and differences in the approaches of the Czech Republic and Great Britain. As a consequence, statistical data were processed; target groups in households were defined and divided into subgroups according to the type and amount of income. Furthermore, the housing stock data helped to establish model buildings. The combination of model buildings and household types enables average energy consumption and the percentage of energy poor households in the Czech Republic to be calculated. Data from Housing Budget Survey (HBS, 2010) and the Czech Statistical Office (CSO, 2014), (CSO, 2015) were used to compare the situation in the UK and the Czech Republic. For the second model, data from the Czech Statistical Office's 2021 Census of Population, Dwellings, and Housing were used (CSO, 2021), supplemented by data from the ENERGO survey (ENERGO, 2021).

6. Statistical data characterizing the current state of households and the housing stock in the Czech Republic

The following chapter describes important factors associated with household expenditures and incomes, their typological distribution, and the characterization of the housing stock in the Czech Republic. These factors need to be monitored in order to gain an overview of the current situation in the Czech Republic. Data that influence energy poverty are monitored, primarily household incomes, household energy consumption (especially for heating), and energy prices for households.

Monitoring statistical data characterizing households is crucial for understanding and measuring the state of energy poverty, primarily for the following reasons:

1. Statistical data on household incomes show how much money households have available to cover basic needs, including energy expenses. Lower incomes can mean that households have fewer financial resources to cover energy costs, which can lead to energy poverty. Households with more financial resources have more options not only to address energy poverty but also to prevent it.
2. Furthermore, closely monitoring statistics on household energy consumption, especially energy consumption for heating, allows for the identification of households that may experience issues with inadequate heating or energy costs that are higher than sustainable.
3. Statistical data on energy prices are essential for evaluating the costs that households incur for energy. Higher energy prices can increase the risk of energy poverty, as energy costs can constitute a larger portion of the family budget.

Monitoring these factors enables the identification of households that may be at risk of energy poverty, a state in which households lack sufficient financial resources to meet their basic energy needs, leading to negative impacts on their living conditions and health.

Since there is no comprehensive database that combines these mentioned three main factors to define the state of energy poverty in the Czech Republic, it is necessary to utilize existing data supplemented as much as possible with categorization and data breakdown. With segmented data, it will be possible to create a model that will characterize households and their state as comprehensively as possible.

6.1 Data characterizing households

The following chapter presents essential statistical data that serve as indicators of the state of energy poverty in the Czech Republic. The data have been selected to characterize Czech households, the houses they inhabit, and other factors that impact energy poverty, such as energy prices, to the greatest extent possible.

6.1.1 Types of fuel used in households

Monitoring the type of fuel households use for heating can provide insights into the type and efficiency of heating systems in use. This can be crucial for assessing energy efficiency and potential emissions of greenhouse gases and pollution associated with different fuels. Categorization based on fuel types can reveal social inequalities and needs. Households that rely on more expensive fuels may be at risk of energy poverty. Information from this categorization can inform policymaking to support these vulnerable groups. Tracking the transition to cleaner fuels can contribute to air pollution reduction and improved air quality.

Table 3 – Distribution of households by main fuel, energy used for heating

	Flats						
	in Total			in Family House		in Apartment House	
	Year		Index	Year		Year	
	2015	2021		2015	2021	2015	2021
Flats in total	4,304,173	4,481,967	104.1	1,830,684	1,932,001	2,473,489	2,549,966
Distribution by main fuel used for Heating							
Electricity	218,512	333,284	152.5	116,013	171,532	113,373	161,753
Natural gas	1,558,002	1,683,055	108.0	994,756	1,043,292	563,246	639,763
Purchased heat	1,740,841	1,704,065	97.9	(9,929)	(14,558)	1,730,913	1,689,506
Solid fuels	544,231	303,876	55.8	495,125	274,079	38,232	29,797
Firewood	193,962	313,290	161.5	172,746	297,557	21,216	15,733
Wood briquettes	-	(14,008)	442.6	-	(10,994)	-	-
Wood pellets	(7,595)	26,947	354.8	(6,680)	24,507	-	-
Heat pump	34,767	91,532	263.3	32,420	89,140	-	-

Source: (ENERGO, 2021)

In the context of developing a strategy to reduce energy poverty in the Czech Republic, tracking the categorization of households based on their primary fuel source is necessary for comparing expenses associated with different fuel types. Data on the distribution of

households by fuel type will be used for an extended model estimating the representation of energy-poor households.

The statistical data in ENERGO 2021 illustrate the distribution of households in the Czech Republic based on income levels and according to the temperature in the most commonly inhabited room. This data reveals how different household groups approach heating within their residences and their approach to thermal comfort.

Table 4 – Distribution of households by temperature and income groups

	Distribution by temperature in the most frequently occupied room						
	≤ 19°C	**20°C**	**21°C**	**22°C**	**23°C**	**24°C**	**> 24°C**
Flats in Family House	1.4	9.5	22.5	35.5	22.1	5.9	3.1
Flats in Apartment building	1.7	8.1	22.8	33.9	22.9	7.2	3.2
Flats total	1.6	8.7	22.7	34.6	22.6	6.7	3.2
Distribution by total net monthly household income							
up to 10 000 CZK	13.0	12.5	21.5	22.2	24.4	3.6	2.7
up to 20 000 CZK	2.5	11.0	22.8	33.8	21.7	5.7	2.6
up to 30 000 CZK	1.7	10.4	22.9	33.1	21.1	7.4	3.4
up to 40 000 CZK	1.3	8.6	23.0	33.4	24.3	6.3	3.1
up to 50 000 CZK	0.9	6.3	22.2	35.7	23.4	7.9	3.6
up to 60 000 CZK	1.1	7.4	21.9	37.8	22.4	6.0	3.4
up to 70 000 CZK	0.2	11.1	21.2	35.8	21.4	6.9	3.6
up to 80 000 CZK	1.6	3.5	25.9	34.7	23.3	8.2	2.8
up to 90 000 CZK	2.0	7.3	20.1	33.9	26.8	5.3	4.7
up to 100 000 CZK	0.0	3.2	28.3	35.2	22.0	9.9	1.4
more than 100 000 CZK	0.9	6.1	21.6	42.9	19.9	6.8	1.9

Source: (ENERGO, 2021)

The Table 4 indicates that households residing in single-family homes have, on average, a nearly identical heating requirement to that of households living in apartment buildings. A slight difference is present, with households in single-family homes heating to 20°C 1.4 percentage points more frequently and heating to 24°C 1.3 percentage points less frequently.

Another interesting statistic that the table illustrates is that 1.6 percent of households in the Czech Republic heat their apartments to below 19°C. Unfortunately, the data does not reveal the reason for this. The cause could be the occupants' thermal comfort preferences, but it could also signify an issue such as energy poverty, where the desired temperature isn't achieved due to financial constraints, leading to a lower indoor temperature to reduce heating costs.

A significant observation is the breakdown based on residents' income, wherein there is a pronounced increase in households heating to below 19°C, particularly for those with an income below 10,000 CZK, accounting for up to 13 percent of households in this category.

Conversely, another trend is evident: households with the highest incomes are far less represented in the group heating their space to 24°C and above. This could be linked to the availability of modern technologies and high-quality properties in terms of energy efficiency, which can provide a more stable and better thermal comfort within the building.

6.2 Household energy consumption

Because energy poverty is closely linked to energy consumption and, consequently, energy expenses, it is necessary to monitor the current energy consumption of households and its trends. The following chapter summarizes essential data on this topic.

6.2.1 Fuel and energy consumption in households

It is important to monitor data on the final consumption of fuels and energy in households as a basis for characterizing the state of households in the Czech Republic. Data on energy consumption by purpose of use can indicate whether households allocate a significant portion of their financial resources to heating, which can be an indicator of energy poverty. If high energy costs constitute a significant share of the household budget, it may suggest issues with energy availability and pricing.

Data on the final consumption of fuels and energy in households are crucial for analysing energy poverty, as they reveal the extent to which households can cover their energy needs in relation to their financial resources.

Table 5 – Final consumption of fuels and energy in households by purpose of use

Fuel/Energy	Total	Year 2020 according to the purpose of use					
		Heating	Hot water	Cooking	Lighting	Cooling	Other
Final consumption	299,272	203,519	49,763	18,922	21,827	233	5,007
Electricity	57,501	10,405	12,136	8,664	21,827	233	4,236
Natural gas	77,707	51,459	16,933	9,315	-	0	0
Purchased heat	40,862	27,576	13,286	0	-	0	0
Solid fuels	26,563	25,819	730	15	-	0	0
Liquid fuels	2,012	1,579	0	433	-	0	0
RES	94,627	86,683	6,678	495	-	0	771

Source: (ENERGO, 2021)

In the scope of this work, the data will be used for model validation. The final household consumption determined by statistical data will be compared with model-generated data. Deviation will be monitored, and the reliability of the created model will be evaluated.

6.2.2 Household Expenditures

The following chapter summarizes household spending and its distribution? across the European Union. In addition, a national comparison showing the distribution of household expenditures is provided. These values are compared with values from other countries relating to various types of households. For the sake of the decision-making process supporting political measures and development of supporting programmes, it is necessary to know the facts pertaining to household spending. This information helps to properly focus on the legislative measures and increase their effectiveness.

6.3 State of the housing stock in the Czech Republic

The following chapter presents important data that characterize the state of the housing stock in the Czech Republic. As there is no available database linking households in the Czech Republic with specific properties and their physical attributes (primarily energy efficiency), the following data will be used as a basis for the created model, which aims to simulate this connection.

It is important to gather data that will create a picture of the housing stock's composition, types of properties, their condition, location, or heating methods. This data will assist in characterizing energy poverty in the Czech Republic, identifying crucial and high-risk areas that need attention and directing efforts towards reducing energy poverty in the country.

6.3.1 Housing and energy expenditures

Housing and energy spending are data important in policy making. The distribution of expenditures and their total amount is one of the primary indicators of the risk of energy poverty. The development of these values in recent years is suitable for creating an estimate of future development. It is necessary to create an appropriate political and legislative environment for protection and home security.

The data in Table 6 show a slight decrease in household expenditure in the European Union between 2014 and 2017. The values represent the percentage of total expenditure. For selected countries the value is very similar. The values show the average status among households, and it is also important to determine whether spending is decreasing in all households or whether it is only an average decline, and some households pay higher amounts than in 2014.

Table 6 – Final percentage consumption expenditure of households for Housing, water, electricity, gas and other fuels

	Housing, water, electricity, gas and other fuels [%]				
State / Year	**2007**	**2014**	**2015**	**2016**	**2017**
European Union (28 countries)	12.6	24.8	24.7	24.4	24.2
Germany	12.7	24.4	24.1	23.7	23.5
Czech Republic	11.9	26.0	25.9	25.7	25.4
Italy	12.4	23.9	23.8	23.4	23.3
United Kingdom	15.6	27.1	27.3	27.0	26.7

Source: (Eurostat, 2019)

For a more detailed view, it is necessary to use data that are divided into several groups. To process further, a data collection for households in the Czech Republic has been used. This data has been divided into five groups according to the population type and level of households' income. The first group consists of 20% of households with the lowest income.

An overview of the development shows the differences between the richest and poorest households. The result of this survey is vital for designing legislation. These documents should focus on opportunities equal for all households and should not cause any damage to certain groups of households. The following table shows the distribution of household expenditure on energy and fuel in each group and indicates the development from 2012 to 2016. The most recent data are available for this period.

Table 7 - Development of households´ expenditure according to net income per person

Types of expenditure	**Average expenditure per person for household in [€] (groups divided based on household income)**				
	I. 20%	**II. 20%**	**III. 20%**	**IV. 20%**	**V. 20%**
Housing, water, energy, fuel (year 2016)	726.3	970.0	1,043.5	1,130.4	1,430.2
Electricity and heat, gas, fuel (year 2016)	395.2	543.3	559.6	598.0	684.8
Housing, water, energy, fuel (year 2012)	684.4	949.6	1,078.3	1,189.1	1,458.6
Electricity and heat, gas, fuel (year 2012)	396.8	552.0	629.7	653.3	730.2
	Development of households´ expenditure				
Percentage of expenditure in 2016 compared to 2012	106.1	102.1	96.8	95.1	98.1
	99.6	98.4	88.9	91.5	93.8

Source: (CSO, 2019)

The table shows a comparison of household expenditure for 2012 and 2016. The data enable to determine the difference of the average expenditure for groups of households. In 2016, the last group spends on Housing, water, energy and fuel almost twice as much as the first group. However, this comparison can be misleading. It is necessary to add information about total income of the households. The value of the proportion of housing expenditure in total revenue is important. It is advisable to compare the status groups.

The second important fact is the difference between 2012 and 2016 as there is decrease in average household expenditure for energy (ranging from 592.4 € to 556.2 € per year). Upon closer examination of the data, it is clear that a decrease of expenditure holds only for certain groups of households. For the first two groups (households of the lowest income), expenditure on Housing, water, energy and fuel has increased. However, other groups have achieved a reduction in their expenditures, e.g. the fourth group achieved expenditure reduction of almost 5%.

For a complete evaluation of the household situation in each group, it is necessary to know the households´ average net cash income. From these values, it is possible to calculate the percentage of household expenditure.

Table 8 – The ratio of household income and expenditure

	Average income per person for household in [€] (groups divided according to household income)				
	I. 20%	**II. 20%**	**III. 20%**	**IV. 20%**	**V. 20%**
Net cash income of the household	2997.8	4370.2	5024.0	5471.6	5958.0
	The share of expenditure compared to net income of households [%]				
The share of expenditure for Housing, water, energy, fuel	24.2	22.2	20.8	20.7	24.0
The share of expenditure for Electricity and heat, gas and fuel	13.2	12.4	11.1	10.9	11.5

(CSO, 2019)

There is a major difference in households' income. The first group of households has less than half of the net income of the fifth group. If the data is compared with the overall cost for housing, the first group has expenses in the amount of 24.2% of their income. For other groups, expenditure gradually reduced to 4%. The expenditure of the last group is lower than the first group by 24.0%. An Objects state occupied by the household and its type has a large impact on the total household´s housing expenditure. It can be assumed that higher income households have larger houses which means higher expenditure.

The resulting data shows that the first group of households achieves higher expenditure for electricity and heat, gas and fuel than for just electricity and heating. Like in the previous case, the percentage of expenditures for the following groups decreases. The last group spends the least. Based on the household income, household expenditures and the distribution of households, it can be assumed that households with lower income live in less energy efficient buildings than households with higher incomes. Potential energy savings would be greater for less income households.

Households with higher income have more opportunities to create reserves or to invest in efficiency measures. There is a great need to help lower income households which have no financial means for any energy-saving measures. As a result, these households are struggling to achieve lower energy consumption in their homes.

6.3.2 Types of houses and their condition

Characterizing the housing stock in the Czech Republic is essential from the perspective of building types, their quantities, and the conditions they are in. Subsequent assistance in reducing the risks or impacts of energy poverty will differ for households living in apartment buildings compared to those living in single-family houses. A distinct approach is required for households living in rentals as opposed to those inhabiting their own property. The approach not only varies in terms of issue-solving possibilities related to energy poverty but also in prevention and mitigating the risk of future developments.

Table 9 – Type of dwelling where the household lives (Percentage representation)

Type of house	Households in Region				
	Total	Prague	Karlovy Vary Region	Zlín Region	Region Vysočina
Detached house	43.3	12.3	27.2	61.7	61.8
Apartment house	56.2	87.7	72.9	37.9	36.7
Other building	0.6	-	-	0.4	1.5

Source: (CSO, 2021)

From the data provided in Table 9, it is evident that households are, on average, distributed in a way that 43% of households live in a detached house, and 56% live in an apartment building. However, when looking at more detailed statistics, significant differences emerge across individual regions. These disparities are primarily driven by local conditions and the historical development of each area. Regions with an agricultural history tend to have more detached houses and rural estates, whereas regions focused on industry and commerce have a different distribution. As a result of this variation, the focus of assistance in reducing energy poverty, including forms of subsidies, must consider the regional context to ensure their applicability in the given area.

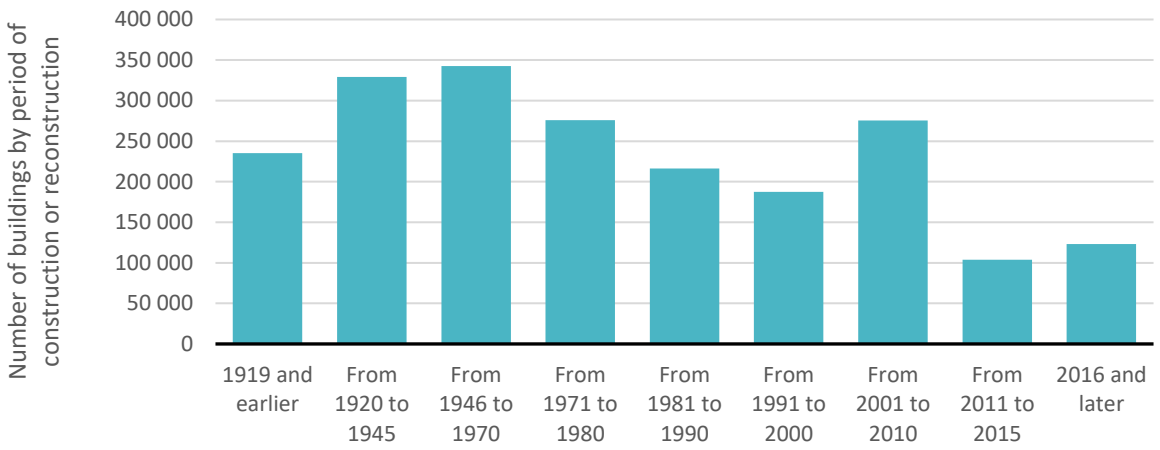


Figure 3 – Housing stock age

Source: (CSO(b), 2021)

Based on the CSO data, it is evident that from the total number of 2,352,055 residential buildings in the housing stock of the Czech Republic, a high percentage were constructed between 1920 and 1980 or earlier. Since thermal and technical requirements for buildings during these years were not as stringent as they are today, it can be stated that structures built during this period exhibit very low energy efficiency.

Table 10 – Apartment size and the percentage of inhabiting households

Total apartment area [m²]	Households in Region				
	Total	Prague	Karlovy Vary Region	Zlín Region	Region Vysočina
< 40	5.6	7.8	5.8	3.7	5.3
40 – 60	17.8	26.9	24.5	14.1	11.1
60 – 80	32.1	34.0	31.9	33.1	32.1
80 – 100	17.6	17.1	11.1	18.4	20.5
> 100	26.9	14.2	26.6	30.6	31.0

Source: (CSO, 2021)

The data presented in Table 10 show differences in the sizes of dwellings in various regions and their deviation from the average in the Czech Republic. This trend corresponds with the previous table displaying types of properties. It can thus be assumed that single-family houses in the Czech Republic, on average, have larger dimensions than apartments in residential buildings. The main reason for monitoring dwelling sizes in the Czech Republic is that the size of a dwelling significantly impacts energy costs, primarily for heating and cooling, and partially for lighting and other appliances. In contrast, smaller dwellings tend to be more energy efficient as they require less energy to reach the desired temperature. Observing dwelling sizes can help identify situations where it is expensive and inefficient to heat or cool a large space that is not fully utilized.

The risk associated with larger dwellings is linked to higher heating costs, which could be one of the causes of energy poverty. One simple but not very practical solution that households might use is reducing or turning off heating in unoccupied parts of a property or dwelling. Inadequate heating of larger dwellings could lead to issues with humidity and mold, negatively impacting residents' health. A smaller dwelling can be better maintained under optimal conditions, thereby reducing the risk of these issues.

7. Ways of tackling energy poverty in the world

7.1 Support programmes in Great Britain

Like most European countries, the Czech Republic has yet to adopt a scheme focusing on the issue of energy poverty. The British subsidy scheme, as the EU leader in measures against energy poverty, can therefore be a source of inspiration when seeking an ideal solution. Some households realise the potential threat of energy poverty and can handle the problem themselves. Sufficient awareness of this issue and its solutions is what is necessary.

7.1.1 Programmes aimed at raising awareness in the area of energy poverty

The "Find energy grants and ways to improve your energy efficiency" programme is the most important programme focused on raising awareness of energy poverty. The programme aims to establish a system to help households raise awareness of the energy situation. The result is an online questionnaire providing households with information about energy and cost saving. The respondent fills in data about his or her current household situation and the state of the building in which he or she lives. Then the respondent obtains a summary table with information about the possibilities to improve their situation and available support schemes. This programme is very useful. In addition to raising awareness about energy issues, it also addresses the imminent threat of energy poverty head on, as households can improve their energy management and resolve their energy issues in time.

Programmes to reduce energy poverty

One of the support schemes that play an active role in reducing energy poverty is Green Deal: energy saving for your home. The scheme focuses primarily on improving the physical properties of the building envelope and on reducing greenhouse gas emissions. The programme involves enveloping of the building, change and improvement of the heating system, replacing windows and generation of renewable energy. This programme can be compared to the "New green to savings" programme in the Czech Republic. Unfortunately, both these programmes have their shortcomings and are not suitable for households affected by energy poverty (Green Deal, 2016).

The "Help from your energy supplier: Energy Company Obligation" programme was introduced in 2013 and aims to reduce energy consumption and help households affected by energy poverty. The programme will require major energy companies to envelope the building and provide adequate measures in the heating system in order to reduce energy

consumption and heating costs. The programme works together with the Green Deal programme, which enables consumers to obtain financial aid. Expenses connected with the above measures are financed by energy suppliers who have to fulfil obligations regarding improvement of the building quality. This programme, or rather its variant, could be introduced in the Czech Republic as well. If energy companies are obliged to help energy poor households that cannot afford adequate access to energy or spend a high percentage of their income on maintaining the heating standard, the households can pay the companies back when they have saved enough money after the measures have been carried out (Energy UK, 2015).

7.1.2 Support programmes indirectly aimed at energy poverty

Great Britain has introduced many other regional programmes aimed at regional or climate issues. The programmes are organised only for a short period of time or under certain conditions, but if they are timed well, they can avert a chain reaction caused by a short-term lack of funding to cover energy expenses.

- The "Cold Weather Payment" programme is designed for winter and runs from 1 November to 31 March. The household may request £25 if the outside temperature falls to zero or below zero for seven days. This programme is not aimed directly at tackling energy poverty but can help in case of a protracted increase of energy consumption (GOV.UK(a), 2016).
- "Winter Fuel Payments" is a programme that may work as an effective measure to tackle energy poverty. It helps by increasing household income. The programme focuses on the elderly, who are one of the endangered types of households. All people born prior to 5 July 1951 are entitled to £100 – 300 to pay their energy expenses (GOV.UK(b), 2016).
- Another programme is "Domestic Renewable Heat Incentive", whose main goal is to reduce carbon dioxide emissions. Programme funds can be obtained for biomass boilers, solar collectors or heat pumps. The money is paid quarterly for a period of seven years (GovUK, 2015).

As discussed above, the Czech Republic has yet to establish any programmes focusing on tackling energy poverty. If the Czech Republic decides to follow the British model of support programmes, the similarities and differences between the two countries as regards households, population and expenses have to be defined first. So far, the Czech Republic has relatively well-developed programmes dealing with reduction of greenhouse gas emissions and final energy consumption. Both these programmes resemble their British counterparts. Nevertheless, the Czech Republic lacks a programme focusing directly on the issue of energy poverty and its solution.

7.2 Comparison of energy efficiency implementation and definition in Europe

Most EU countries lack the definition of energy poverty, but this approach is likely to change, thanks to the new EPBD (iii) which is to tackle energy poverty. This document indicates that the need to alleviate energy poverty should be taken into account in accordance with the criteria set by the Member States. The Member States have the right to determine what actions they consider relevant in this respect.

Each of the EU states should develop a long-term recovery strategy document that would support the renovation of the national stock of residential and non-residential buildings. At the same time, the strategy document should outline relevant national measures contributing to energy poverty alleviation.

Since most Member States do not have their own definition of energy poverty, it is recommended to get inspiration from those states that are already dealing with the issue of energy poverty. Consequently, these definitions can be transposed and applied in other Member States. The following list encompasses energy poverty definitions carried out by various EU Member States which are already dealing with the issue of energy poverty and mention it in their legislation:

Definition of Energy Poverty – United Kingdom

A household is in fuel poverty if, in order to maintain a satisfactory heating regime, it has to spend more than 10% of its income (including Housing Benefit or ISMI) on fuel. A 'satisfactory heating regime' is defined as one that achieves 21° C in the living room, and 18° C in other occupied rooms.

Definition of Energy Poverty – Cyprus

Energy poverty may relate to the situation of customers who may be in a difficult position because of their low income as indicated by their tax statements in conjunction with their professional status, marital status and specific health.

conditions, and, as a result, are unable to respond to the costs for electricity supply which represent a significant proportion of their disposable income.

Definition of Energy Poverty – France

The social and economic situation of a household (conjunctural or high quality) depends on the context of a housing crisis. It concerns those whose social, economic and environmental vulnerability prevents them from heating adequately or paying energy bills. (French-Property, 2018)

Definition of Energy Poverty – Ireland

Energy poverty is a situation whereby a household is unable to attain an acceptable level of energy services (including heating, lighting, etc) in the home due to the inability to meet these requirements at an affordable cost. (Assist2gether, 2017)

Definition of Energy Poverty – Slovakia

Energy poverty means difficulty or inability to keep appropriate temperature conditions in the dwelling as well as difficulty or inability to keep other basic energy services at reasonable cost. According to the World Health Organization, 21°C is considered a comfortable room temperature in the living room while 18°C in other rooms. (VEnergetikce.sk, 2018)

The essence of all the above-mentioned definitions is the same. The main principle of defining energy poverty is very similar and the definitions differ only in subtle nuances. It is very difficult to determine which household falls in the category of energy poverty and which does not yet, as it depends on many factors. For each Member States is important to assess the precision of the definitions before adopting them in the national legislation. It must be examined whether it is possible to implement them in their existing form. Furthermore, it is important to examine other factors that are necessary, such as national climatic conditions, the state of the economy, the state of the housing fund and others.

8. Model for estimation of endangered households

To get a better overview of the situation of the energy poverty issue in the Czech Republic, it is necessary to know how large a share of households is affected by energy poverty. There are no available data that directly address the issue of energy poverty and affected households, so it is necessary to find out this information from other available data.

The first model developed is intended to enable the estimation of households in the Czech Republic. Due to the lack of available data to determine the extent of households affected by energy poverty, a model based on available statistical data was developed and the results were used to estimate the number of households affected by energy poverty.

Model classification:

Mathematical descriptive static model, deterministic model.

8.1 Description of model

The first model was created for a simple estimate of the number of energy-poor households in the Czech Republic. A deterministic model format was chosen, utilizing input statistical data. The model's inputs consist of data on household incomes, which are categorized into five groups based on income levels, and further divided into two subgroups based on the number of earning individuals or the number of household incomes. The second input into the model is data on the size and type of dwelling. The model is calculated for the categories of single-family houses, apartment buildings, and panel houses. Based on data regarding the number of rooms in the dwelling, an estimate of the heat requirement for heating is determined.

Given the lack of a detailed analysis of energy-poor households, their incomes, and their structure in the Czech Republic, the following model provides an estimate of vulnerable households. Based on the building's characteristics, model objects were created for which average energy consumption was calculated. Energy consumption was determined based on heat transfer through structures and the heat loss of model objects. Based on the heating requirements of the object and energy prices, average household expenses in various groups were determined. Households were divided into groups based on:

- The type of dwelling in which they reside:
    - Single-family houses
    - Apartment buildings - panel, brick
- Household incomes (Based on statistical income data and their distribution according to quantification):

- Households were divided into 5 groups based on 20% income intervals.
- Calculations were performed separately for single-income households and households with two or more incomes.
- The size of the dwelling based on the number of rooms.

The following chart illustrates the principle of the model calculation. The calculation's primary output is the comparison of household incomes and energy expenses for heating. This process was carried out for a total of 180 groups according to the previously mentioned categories. Energy poverty was determined based on the average ratio of incomes to expenses. A threshold of 10% of income spent on heating was chosen to determine energy poverty. If the ratio exceeded the established threshold, the group was labelled accordingly. The estimate of the number of energy-poor households was made based on the representation of the number of households in the designated groups.

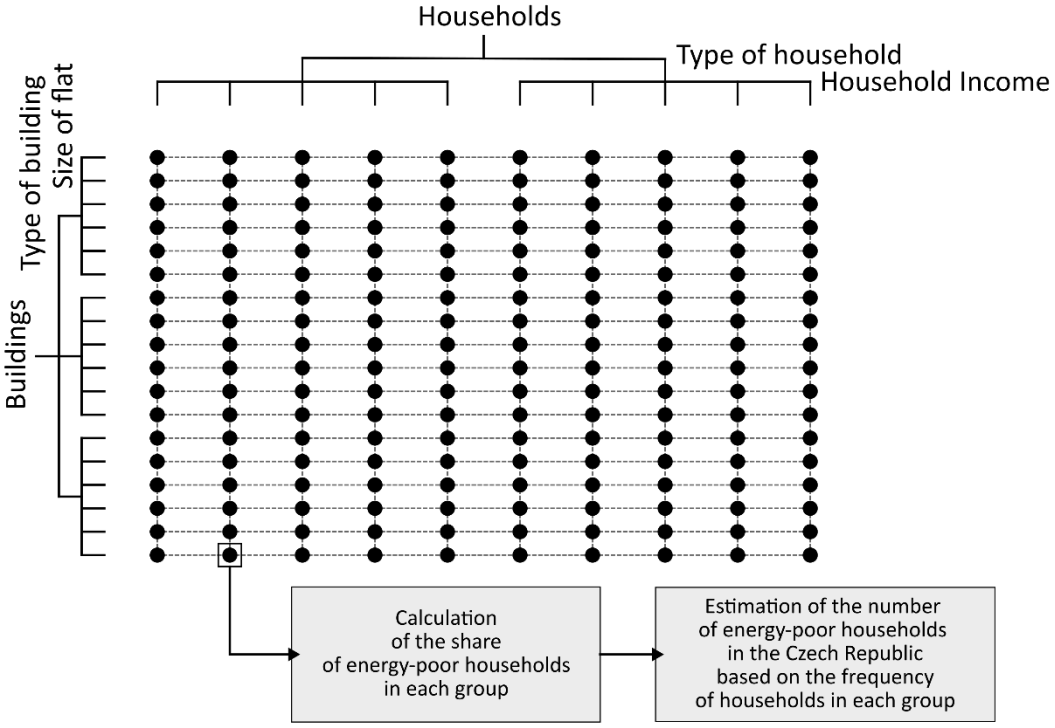


Figure 4 - Diagram of the model calculation for estimating the number of energy-poor households

Average energy losses and energy consumption were calculated for object categories. Calculation is based on statistical data, especially useful areas and building envelopes. Households were divided into five income categories. For each category, the average household income was compared to the cost of the building. Estimates of the representation of energy poor households were determined based on the results.

The equation 1 presents estimation of the percentage of household's expenses to energy:

$$\mathrm{PHE} = \mathrm{EA} \,/\, \mathrm{IE} * 100 \qquad (1)$$

PHE *the percentage of household's expenses to energy in a category;*
EA *Anticipated expenses to cover the energy consumption for a type of object;*
IE *Estimated income households living in a type of object and its size.*

Based on the statistical data it is possible to estimate the distribution of the energy poverty Czech households. Model objects have determined the average energy requirement for the type and size of the object. The power consumption curve was determined based on the size of the building and the year of construction. The calculation used the size distribution of the object based on statistical data. Such estimation is provided according to the frequency of the individual categories in relation to their representation.

$$\mathrm{HEP} = \sum (\mathrm{PHE} * \mathrm{FOT} * \mathrm{FOS} * \mathrm{FHT} * \mathrm{FHS}) \qquad (2)$$

HEP *The percentage of energy poor households;*
FOT *Frequency coefficient for the object type;*
FOS *Frequency coefficient for the object size;*
FHT *Frequency coefficient for the household type;*
FHS *Frequency coefficient for the household size.*

Source: author

Provided that the model-based situation is transferred to a real situation and a corresponding number of households is assigned to each category. Based on the equation 2, it is possible to estimate the percentage of energy poor households.

9. Model for Estimation of the Distribution of Energy Poverty in the Regions of the Czech Republic

The first model for estimating the number of energy-poor households is rather inadequate for use in a more detailed analysis of the issue. A second model was created, primarily focusing on the structure of households and apartments. As numerous new parameters are introduced into the model, it was developed as a stochastic model. Many input values are derived from statistical data, which inherently carry their own uncertainties. By opting for a stochastic model, it becomes possible to work with this uncertainty as well.

Model classification:

Mathematical descriptive dynamic model, stochastic model.

9.1.1 Description of the model

The thesis includes the development of a model to estimate the distribution of energy poverty among households in the Czech Republic. The model is based on statistical data. Input data of the model are statistical data of households, dwellings and energy from the Czech Statistical Office.

The model that is used in the thesis is a form of mathematical model. Unlike the first model, it has been developed as a Stochastic model. The choice of the stochastic form of the model was chosen because of the greater possibilities of working with the model and because of the imprecise input data. The model is intended to more closely approximate real events and thus cover possible combinations of input data that may occur in reality.

The model is based on two levels of random variables, where the first level is to generate random households based on the probability of their characteristics (Household Composition, Type, Location, etc.). In the second level, the generated household is augmented with data based on statistics that are random in a predetermined between (Household Income). Once the random variables have been generated, the model calculates the remaining variables needed for the household in a deterministic manner for the final evaluation.

For faster workflow in generating random variables and their evaluation, the programming language C# and the development environment Visual Studio were chosen for building the model. The fundamental calculation principle is depicted in the diagram, and a sample source code is provided in Appendix A.

9.1.2 Model validation

Verification of the basic values of the model is carried out based on the average values of input data, which are constructed using statistical data available from the Czech Statistical Office. These values are compared with the generated values of the model, and the deviation of these values from the established average values is sought.

Since the model operates using the Monte Carlo method, which involves random values generated according to the given parameters, the mean value of the set of generated values is compared with the average value obtained from the statistical data.

The following values were selected for model verification:

- Average number of households in a given region;
- Average number of households with a specific head of household;
- Average monthly household income;
- Average monthly household income per person;
- Average apartment area;
- Average expenditure on heating.

As part of the verification, 1,000 random households were generated each time to calculate the average value. This process was repeated 100 times, and from these 100 average values, the mean and variance were calculated. These calculated values were then compared with the average value obtained from the statistical data.

9.1.3 Model input data

The structure of the model's input data can be divided into three main categories: statistical data characterizing households in the Czech Republic; data on the characteristics of dwellings and buildings in which households live; and data related to household energy prices.

Structure of input data:

- Household characteristics:
    - **Distribution by region;**
    - **Distribution by head of household;**
    - **Number of persons in the household;**
    - **Household income.**
- Dwelling characteristics:
    - **Type of the building;**
    - **Age of the building;**
    - **Average size of the dwelling;**

- **Heating method of the dwelling.**

- Energy data:
  - **Energy price by commodity type.**

The database of data relating to the age and type of building is used as a basis for calculating the average consumption of a household building. For each type and age of building, the **average energy consumption** is calculated as a function of its area. This figure is then taken as one of the other inputs to the calculation model.

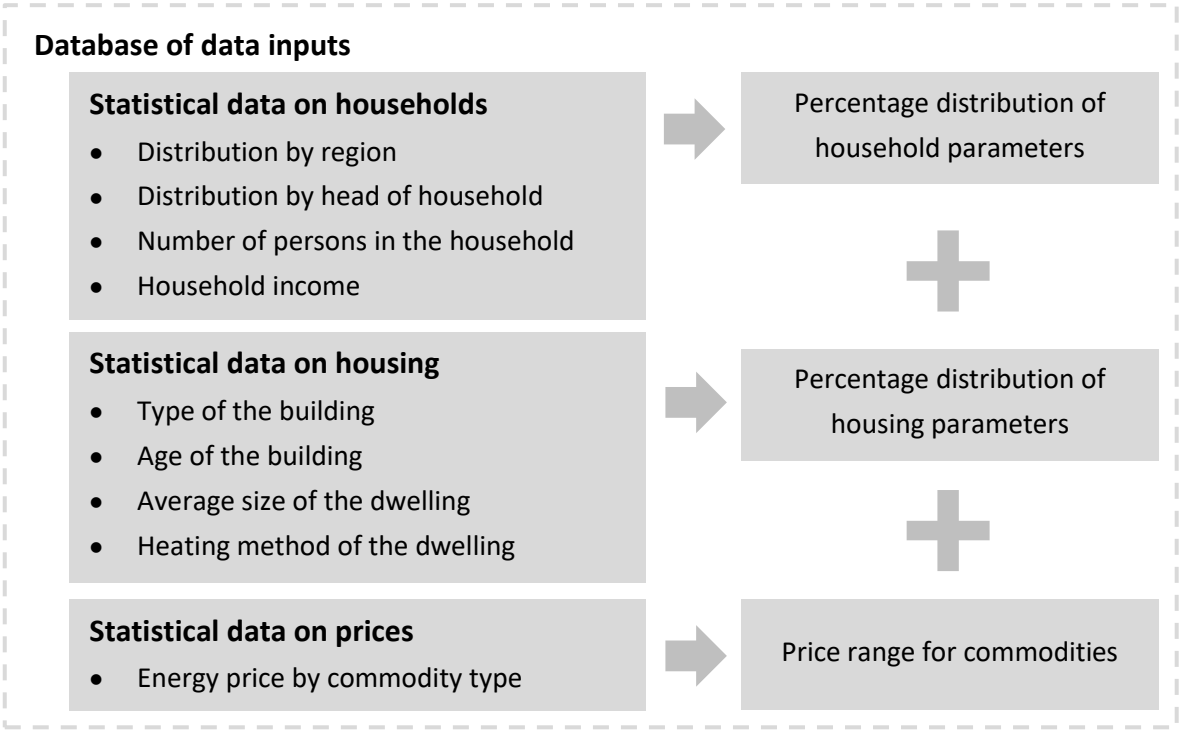


Figure 5 – Diagram of the use of statistical data for input to the model

9.1.4 Calculation methods

The model is based on generating random households that have characteristics typical of households in the Czech Republic. The household properties are determined based on statistical data.

The model incorporates three main groups of input data. The first group consists of statistical data, which are used to establish the probabilities of household properties in the model. For each generated household, a property is assigned based on the probability influenced by already generated properties. The hierarchy of household properties is as follows:

Household > Region > household type > household income > building type >
> apartment/house size > building age > heating requirement > heating method >
> heating expenses.

The detailed dependencies of individual input data are displayed in the following diagram, illustrating the process of assigning properties to the generated household and calculating the household's energy expenses.

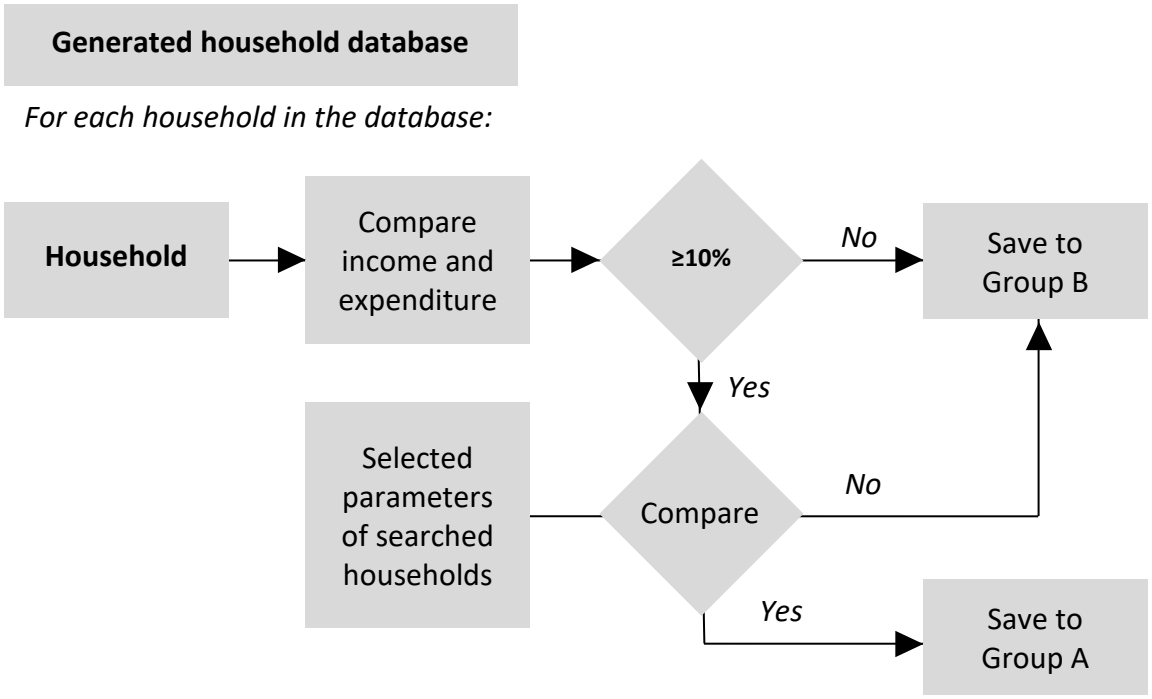


Figure 6 – Energy poverty assessment logic diagram

The model is based on the creation of a household database, where properties are assigned to households based on available statistical data. These households are then compared to selected parameters, and households that can be identified as energy-poor are sought. The calculation is set to define energy poverty, which has been adopted from the definition used in the United Kingdom because it is easily quantifiable and has a clear threshold. The primary goal of the model is to determine the number of energy-poor households (Group A) within the entire dataset of households. The model allows for data analysis based on extracted parameters that match the statistical data (e.g., distribution by regions, household heads, building age, building type, etc.).

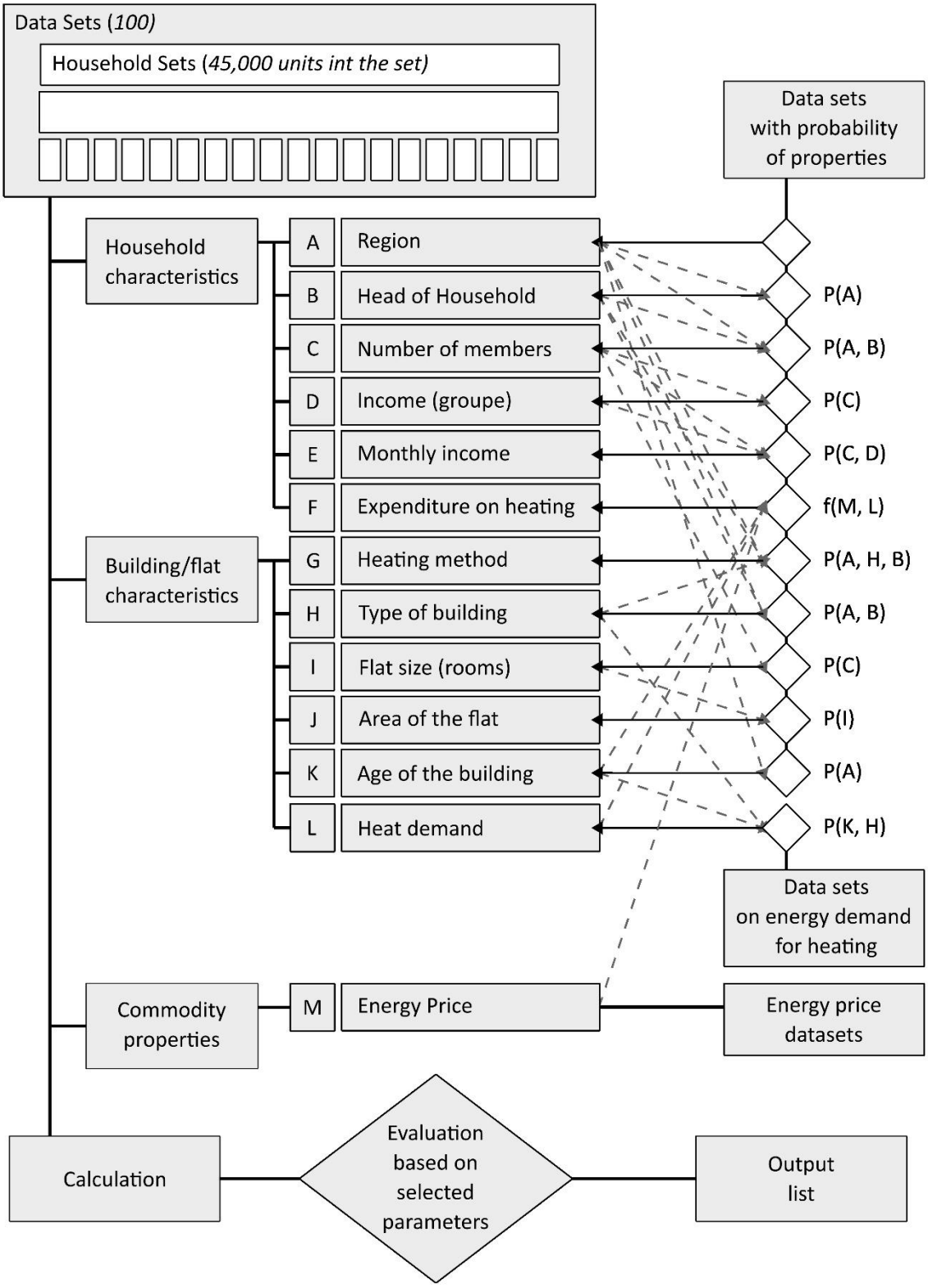


Figure 7 – Diagram of the model logic for estimation of Energy Poverty

Groups of input data:

The first group of input data for the calculation is a generated set of households representing households in the Czech Republic. This data is purely based on statistical information and is assigned to households based on probabilities.

The second group of data relates to the heating of the building. Based on calculations, prices per kWh for different heating methods have been determined. These prices are assigned to households based on their heating method, with a random value generated within a specified range. The value is generated using a uniform distribution based on minimum and maximum values. The minimum and maximum values are determined through separate calculations and entered the model as individual input values.

The third group of data pertains to the heating requirement. Calculations have been conducted to determine the heat demand for heating based on the building envelope used at the time of construction. The input data is a combination of multiple sources, including a calculation based on the energy balance of reference buildings and another source described in the chapter.

Distribution of random variables

The basis of the model is to generate a random household that is assigned properties based on probability. The probability is determined based on available statistical data. The generation of the household properties is in a hierarchical sequence where the already generated values are used to determine the following values.

A uniform distribution is used for the values in the second level of generated values. The uniform distribution was used because of the large number of categories among which the data are divided and the unavailability of more detailed data to describe the distribution in more detail. For example, nine categories are created for household income by income level, these categories are taken from available statistical data and have been assigned probabilities. Each category contains a range of income, which is generated in the second level of the model once the category is selected.

Example of generating household characteristics in the first level - the amount of household income:

$$H_{inc,cat} = f(Rd(\mathrm{S}_C)) \tag{3}$$

$Rd(S_C)$ *Random value to determine the appropriate category, the value is generated in a uniform distribution (from 0 to S_C);*

$f(x)$ *Income group category assignment function to the generated household, the category is assigned based on the generated value and probability distribution;*

$H_{inc,cat}$ *Household income category (includes minimum and maximum income levels)*

$$\sum R_{inc,cat}(H_{type}, H_{Head}, H_{Loc}) \quad (4)$$

S_C *Sum of representations in the respective category*

Table 11 - Example of probability distribution of the choice of household income category

Category of Household income	Representation in the relevant category $R_{inc,cat}(H_{type}, H_{Head}, H_{Loc})$
Category A (up to 6 000)	5
Category B (6 001 – 8 000)	364
Category C (8 001 – 10 000)	874
Category D (10 001 – 12 000)	1580
Category E (12 001 – 15 000)	1981
Category F (15 001 – 20 000)	2826
Category G (20 001 – 30 000)	2338
Category H (30 001 – 50 000)	398
Category I (50 001 and more)	12

After assigning a category to a household, a second random variable generation occurs where a random value of household income is generated based on the assigned minimum and maximum category values.

$$H_{inc} = R(H_{inc,cat,min}, H_{inc,cat,max})) \quad (5)$$

$R(min, max)$ *A random value based on the interval min, max, value is generated in the uniform distribution;*

$H_{inc,cat,min}$ *Minimal value of household income category;*

$H_{inc,cat,max}$ *Maximal value of household income category;*

H_{inc} *Household income (in CZK).*

The process shown in the previous equations is for one combination of properties of the generated household. For other characteristics, for example, when the location of the household changes, the data changes and the probability of the category and subsequently the income level is generated from different values.

9.1.5 Output data

The output of the model is not a single resulting value, but the model allows to observe a group of values that characterize the model properties of households in the Czech Republic. Based on the output data, it is possible to estimate the representation of households

affected by energy poverty in the Czech Republic, the distribution of energy poverty among regions, or to estimate the development of energy poverty in the future.

Generated group of households

The mathematical model is set up to generate 45,000 households in 100 sets. Each set should represent a picture of the situation in the Czech Republic. The mean value of the set is taken as the output value. For example, the number of households that spend more than 10% of their income on heating is calculated as the mean of the number of households in each set. The mean value is supplemented by the standard deviation. The results are in the format of mean ± 2x standard deviation (for 95% coverage).

$$EP_{\bar{x}} = \frac{1}{N}\sum_{i=1}^{N}(EP_i) \tag{6}$$

$EP_{\bar{x}}$ *Mean value of generated sets.*
EP_i *The average value in the generated set i.*
N *Number of generated sets.*

$$EP_{\mathrm{SD}} = \frac{1}{N-1}\sum_{i=1}^{N}(EP_i - EP_{\bar{x}})^2 \tag{7}$$

EP_{SD} *Sampling standard deviation of generated sets.*

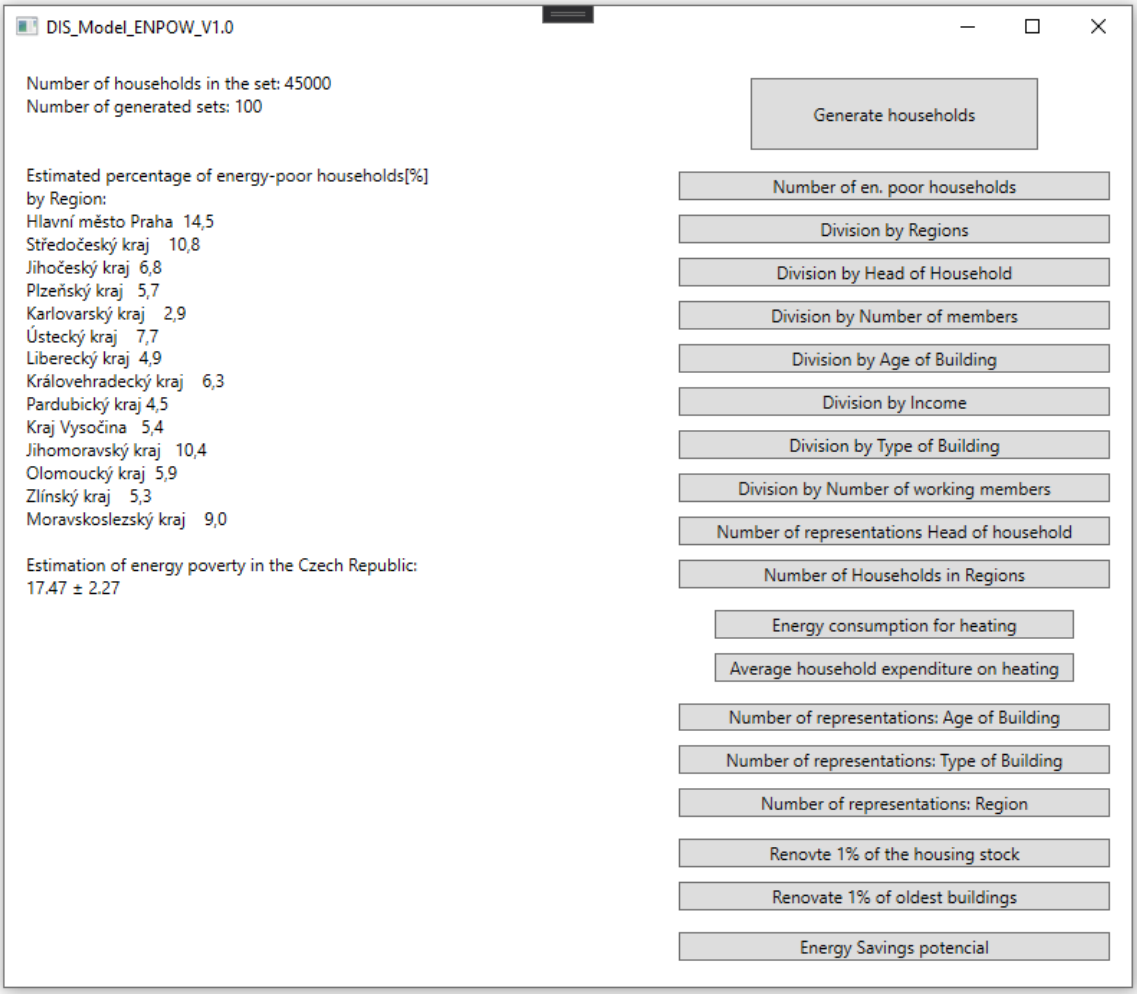


Figure 8 - Model Output Panel

The model calculation runs in the background of the programme upon pressing the "Generate Households" button. The user interface is simple, intended solely for displaying computed results. The model allows toggling the display of results among selected categories or performing new household file generation. Input parameter settings, calculation procedures, and the number of generated households are specified within the program's source code.

Estimate of the number of households affected by energy poverty

The output of the model is the total value of households that meet the set threshold. A threshold of 10% of household income spent on heating was chosen. This threshold was set based on a survey of energy poverty definitions abroad. It was chosen because of the precision of the threshold and the easy verifiability of the data.

A sensitivity analysis was carried out to show the sensitivity of households in the Czech Republic to the setting of this threshold.

Estimation of the distribution of energy poverty in the Czech Republic

The data in the model can be grouped into categories based on the input data. It is possible to calculate a separate result for each category and compare them with each other. The following categories can be selected for the output data:

- Region;
- Head of the household;
- Type of building;
- Household income level category;
- Education of the head of household.

Estimation of energy consumption in the buildings of energy-poor households

Based on the generated values and the determined category, it is possible to analyse the consumption in buildings that fall into the energy poverty group. On the basis of this calculation, it is possible to calculate an estimate of the potential energy savings that can be achieved if appropriate measures are chosen.

Estimation of the development of energy poverty

After expanding the model, it is possible to forecast the potential development of energy poverty in the Czech Republic. This prediction is based on the evolution of energy prices and household incomes. Specific model outputs are provided in Chapter 10. An estimate of the increase in energy-poor households by 2030 has been calculated based on defined scenarios. Furthermore, an estimate of potential energy savings offered by energy-poor households has been conducted, which could contribute to the state's environmental goals.

10. Results

The following chapter presents the results achieved through calculations and created models to determine the current state of energy poverty in the Czech Republic. Households affected by energy poverty are being identified. The results include an estimation of the distribution of energy-poor households based on household types, building ages, household incomes, etc. The calculation also includes a projection of developments up to 2030 based on the current trends in energy prices, household incomes, and their characteristics. The potential benefits of energy savings when addressing the issue of energy poverty in the Czech Republic have been calculated.

10.1 Current situation in the Czech Republic

Programs to address energy poverty in the Czech Republic are still underdeveloped, leading to a lack of informational resources to assess the current situation in the country. As a result, we can rely either on foreign analyses or on statistical data. Energy prices strongly affect household expenditures. Rising energy prices can pose significant difficulties for many households that will be unable to manage the expenses despite efforts to achieve maximum energy savings.

While general awareness of this topic has increased, energy poverty can still threaten many households. Although households may succeed in reducing energy consumption, they cannot control external factors. Growing energy prices, for example, pose a threat to their incomes that they can no longer cover, meaning they will have to start saving. Household savings will likely start with other expenses before affecting heating, but sooner or later, this will impact comfort levels. Another way to reduce energy expenses is to stop heating unused parts of the house, which, however, leads to their deterioration over time.

10.2 Estimation of the number of households affected by energy poverty in the Czech Republic

To map the current situation, we need detailed information about all households and buildings in the Czech Republic. As there is no official national database of energy poor households available, it is necessary to apply another method in order to determine the exact number of households suffering from energy poverty. A smaller database of buildings and households that would characterise the current situation in the Czech Republic seems to be a suitable option.

The data about households were taken from the Czech Statistical Office. Six categories of households were established. The most important information was the average income of

the given category, which served as a model for calculating the estimate (in percentages) of household energy expenses (CSO, 2016).

Like households, the buildings were divided into categories according to type, size and age. All these parameters influence the overall energy consumption. For model buildings representing particular categories.

Households subdivided into five categories according to their level of the income. Each group represents 20% of households. The distribution of groups helps to map the situation. The calculation enables to data for particular categories of households in relation to the size of their flats to be displayed. The values of Table 1 show the percentage of households in the given categories whose expenditure exceeds 10% of their income.

Table 12 – Estimated number of energy poor households in CZ

Type of household:	Estimated percentage of potentially energy poor households based on the type of building [%]
Single-income households in family houses	7,83
Multi-income households in family houses	2,59
Single-income households in apartment houses	5,21
Multi-income households in apartment houses	0,37
Estimated percentage of energy poor households	**16,0**

In Table, it is significant that single-income families living in family houses are the most endangered types of households. It is caused by the lower income available to the households and by the fact that in order to keep the building heated lower income households have to spend the same amount of money as households with higher income. A single-income household has reduced or minimised heat expenditure thanks to lower water need. On the other hand, the need of heat increases on the grounds of lower heat gain.

The model can also be used to estimate the development of the percentage of energy poor households in the Czech Republic. If the rise of energy prices in the last decade is taken into account, it is possible to estimate potential development in the near future. If new values are inserted in the model, we obtain an estimate of 29% of energy poor households in 2025 and more than 40% in 2050. Although these numbers make estimations based on statistical data only, it is clear that the housing fund must be provided for.

Table 13 – Share of energy expenditure on heating, households in the Czech Republic

Percentage of household energy expenditure according to the type of household and size of the flat

Type of household		**Number of rooms in the flat**					
Single-income households (SIH)		1	2	3	4	5	6 and more
Two and more-income households (TMIH)		**Percentage of household thermal energy expenditure**					
Family houses							
SIH	First 20%	4,9	9,9	**14,9**	**21,7**	**28,5**	**31,2**
	Second 20%	3,6	7,3	**10,9**	**15,9**	**20,9**	**22,9**
	Third 20%	3,3	6,6	9,9	**14,4**	**19,0**	**20,8**
	Fourth 20%	3,6	7,4	**11,0**	**16,1**	**21,2**	**23,2**
	Fifth 20%	2,8	5,7	8,5	**12,4**	**16,3**	**17,8**
TMIH	First 20%	2,7	5,5	8,3	**12,0**	**15,8**	**17,3**
	Second 20%	2,0	4,0	6,1	8,8	**11,6**	**12,7**
	Third 20%	1,8	3,7	5,5	8,0	**10,5**	**11,5**
	Fourth 20%	2,0	4,1	6,1	8,9	**11,8**	**12,9**
	Fifth 20%	1,6	3,1	4,7	6,9	9,0	9,9
Apartment buildings in brick							
SIH	First 20%	5,0	8,3	**12,4**	**13,2**	**16,5**	**19,8**
	Second 20%	3,6	6,1	9,1	9,7	**12,1**	**14,5**
	Third 20%	3,3	5,5	8,2	8,8	**11,0**	**13,2**
	Fourth 20%	3,7	6,1	9,2	9,8	**12,3**	**14,7**
	Fifth 20%	2,8	4,7	7,1	7,5	9,4	**11,3**
TMIH	First 20%	2,8	4,6	6,9	7,3	9,2	**11,0**
	Second 20%	2,0	3,4	5,0	5,4	6,7	8,1
	Third 20%	1,8	3,1	4,6	4,9	6,1	7,3
	Fourth 20%	2,0	3,4	5,1	5,5	6,8	8,2
	Fifth 20%	1,6	2,6	3,9	4,2	5,2	6,3
Panel houses							
SIH	First 20%	2,4	4,8	7,2	9,6	**11,9**	**14,3**
	Second 20%	1,8	3,5	5,3	7,0	8,8	**10,5**
	Third 20%	1,6	3,2	4,8	6,4	7,9	9,5
	Fourth 20%	1,8	3,5	5,3	7,1	8,9	**10,6**
	Fifth 20%	1,4	2,7	4,1	5,5	6,8	8,2
TMIH	First 20%	1,3	2,7	4,0	5,3	6,6	8,0
	Second 20%	1,0	1,9	2,9	3,9	4,9	5,8
	Third 20%	0,9	1,8	2,6	3,5	4,4	5,3
	Fourth 20%	1,0	2,0	3,0	3,9	4,9	5,9
	Fifth 20%	0,8	1,5	2,3	3,0	3,8	4,5

The sooner an energy poverty programme is established, the sooner savings measures can be carried out and more cumulated energy savings can be achieved. Construction works necessary for the energy savings measures will be more expensive in the future and using energy inefficient buildings will lead to primary energy waste.

10.3 Estimation of the distribution of energy poverty in the regions of the Czech Republic

Because the results from the first model are only applicable for estimating the number of energy-poor households in the Czech Republic, a second model was created to better characterize households. The following subchapters present important results of the model calculations. Their main task is to provide more detailed information about the distribution of energy poverty among households in the Czech Republic and predictions and scenarios of possible development in the coming years.

10.3.1 Results of model calculations

The first output of the model is a look at the overall representation of households affected by energy poverty in the Czech Republic. An energy poor household is defined as a household that spends more than 10% of its income on heating the building. Because the models are based on different calculation principles, the overall estimate of the representation of households spending more than 10% of their income on heating energy differs. It can be assumed that the results of the second model are more accurate because the characterization of households and groups of households in the model is more detailed. The model is extended by a standard deviation within which the results of both models overlap.

For the calculation, 45,000 households in the set were generated. A total of 100 sets of households were generated. Based on the calculation set out in the equation 6 and 7, the result was obtained:

Table 14 - Estimation of energy poverty in the Czech Republic (Second model)

	Estimation of percentage representation [%]		Standard deviation of percentage estimate
Households affected by energy poverty in the Czech Republic	**17.47**	**±**	**2.27**

Based on the estimation of the prevalence of energy-poor households in the Czech Republic, it is possible to determine the number of households that correspond to this criterion. Taking into consideration that there are currently 4,813,103 households in the

Czech Republic, there are therefore a total of **731,600 to 950,100** households that can be characterized as **energy-poor households**.

10.3.2 Estimation of the representation of energy-poor households according to the model

The output of the model includes not only estimates of the prevalence of energy poverty in the Czech Republic but also the ability to display data categorized by input data. This means that it is possible, for example, to calculate the number of energy-poor households in each region or assign the counts of energy-poor households to categories such as household head, education level of household members, building type, building age, etc.

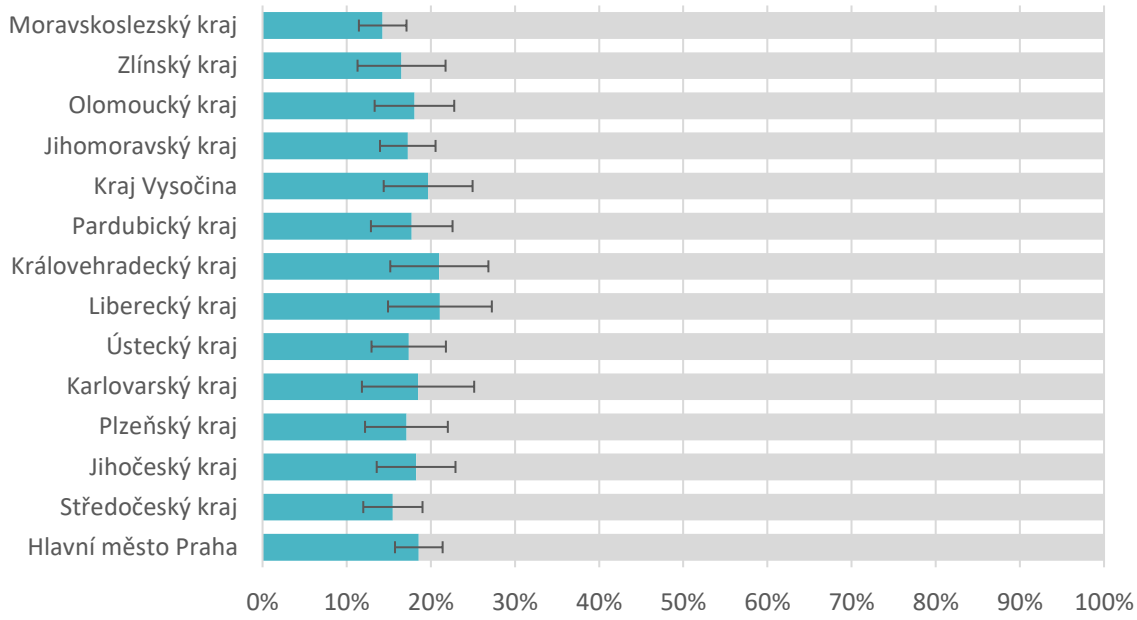
Estimating the distribution of households based on multiple criteria allows for a deeper understanding of the issue of energy poverty. The new data will assist in targeting strategies and individual support programs. With a greater understanding of the target groups, assistance can be more precisely focused to increase its effectiveness.

The proposal for a programme aimed at reducing energy poverty in the Czech Republic must be based on the local conditions of households. It is essential to take into account their current situation and possibilities, not only in terms of their financial circumstances but also concerning the type of dwelling they reside in. Different approaches must be taken for a household living in a rural area in their own single-family house versus a household living in an urban setting within a historic rented apartment building.

Table 15 – Estimated representation of energy poverty in each category: Type of the building

Type of building	Estimated percentage of energy-poor households [%]
Family House	21,36 ± 1,72
Apartment House	15,17 ± 1,17

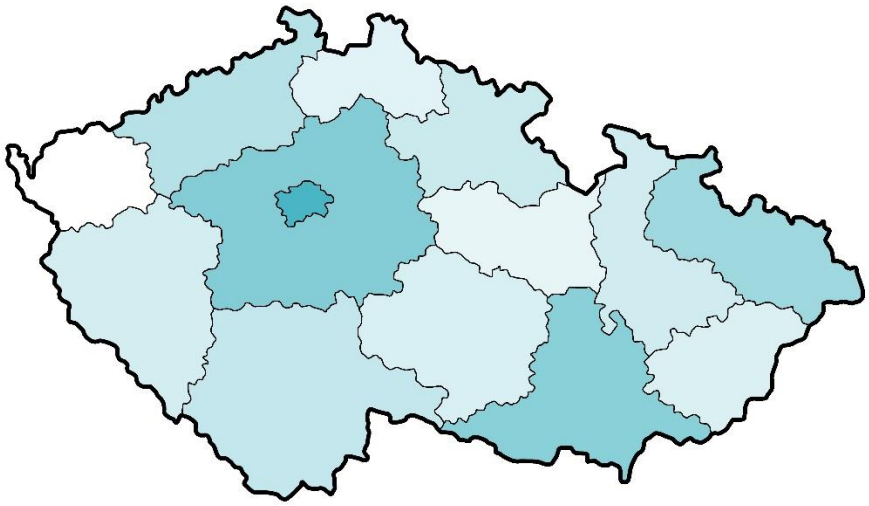
Based on the conducted calculation, the probability of energy poverty was determined for the categories of single-family houses and apartment buildings. Due to technical parameters, physical properties, and the sizes of building structures in the Czech Republic, within the Family House category, 21% of households are affected by energy poverty compared to 15% of households in apartment buildings.



Region	Estimated percentage of energy-poor households for each region of Czech Republic [%]
Hlavní město Praha	18,57 ± 2,83
Středočeský kraj	15,49 ± 3,52
Jihočeský kraj	18,25 ± 4,68
Plzeňský kraj	17,10 ± 4,92
Karlovarský kraj	18,48 ± 6,67
Ústecký kraj	17,37 ± 4,42
Liberecký kraj	21,08 ± 6,17
Královehradecký kraj	21,01 ± 5,83
Pardubický kraj	17,73 ± 4,85
Kraj Vysočina	19,68 ± 5,28
Jihomoravský kraj	17,26 ± 3,30
Olomoucký kraj	18,05 ± 4,73
Zlínský kraj	16,52 ± 5,23
Moravskoslezský kraj	14,28 ± 2,83

Figure 9 – Estimated representation of energy poverty in each category: regions of Czech Republic

The previous output of the project demonstrates the likelihood of energy-poor households occurring in various regions. The resulting values are individually related to each region, so they do not provide information about the overall distribution in the Czech Republic but rather pertain to each region separately. The assessment of estimating the representation of energy-poor households involves a large number of parameters that are determined based on statistical data.



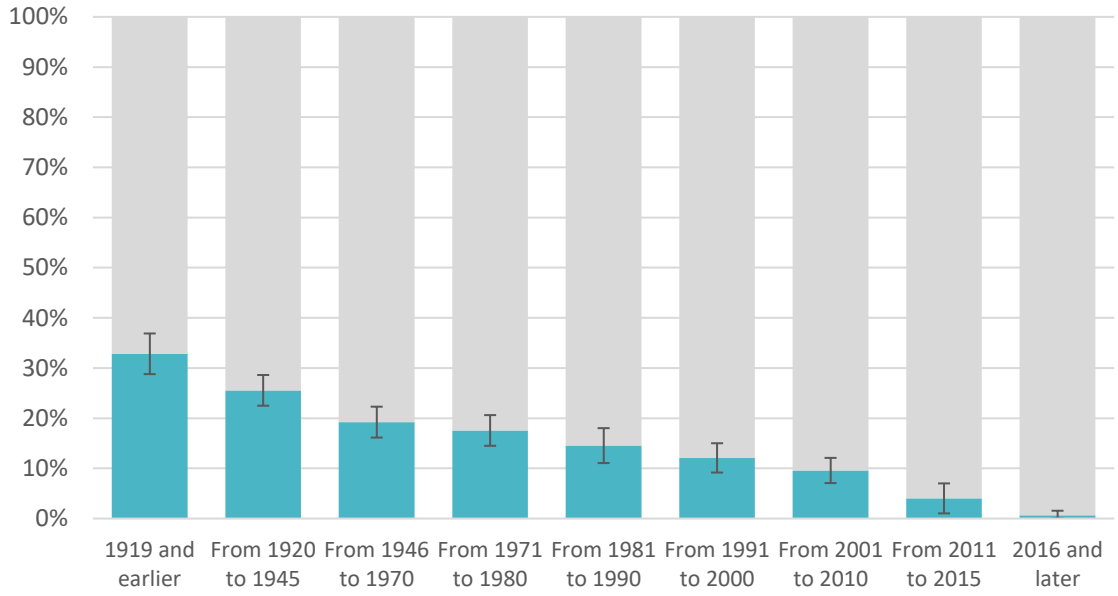
Region	Estimated percentage of energy-poor households [%]
Hlavní město Praha	14,5
Středočeský kraj	10,8
Jihočeský kraj	6,8
Plzeňský kraj	5,7
Karlovarský kraj	2,9
Ústecký kraj	7,7
Liberecký kraj	4,9
Královehradecký kraj	6,3
Pardubický kraj	4,5
Kraj Vysočina	5,4
Jihomoravský kraj	10,4
Olomoucký kraj	5,9
Zlínský kraj	5,3
Moravskoslezský kraj	9,0

Figure 10 - Estimation of representation of energy poverty in regions of Czech Republic

Based on the created model, an estimate of the distribution of energy-poor households among the individual regions in the Czech Republic has been determined. From the values, it is evident that regions with lower income levels are more affected, with predominantly single-family houses rather than apartment buildings. A special case is the region of the Capital City of Prague, where there is a relatively high representation of energy-poor households. This fact is attributed to the prevalence of larger apartment units, which have a larger footprint compared to other regions. Additionally, there is a high proportion of properties with a historical background in this area. Due to either lack of energy-efficiency reconstruction or historical preservation reasons, full energy-efficiency upgrades are not feasible for these properties.

The figure illustrates the estimated distribution of energy-poor households in the Czech Republic. Despite the relatively balanced percentage distribution shown in the figure, the significant share of regional population heavily influences the overall distribution. This

share significantly contributes to the distribution of households that allocate more than 10% of their income to heating expenses. Hence, it can be affirmed that the highest number of energy-poor households, considering an energy-poor household as one that spends more than 10% of its income on heating costs, is in the most populous regions of the Czech Republic. The influence of local housing funds and income disparities plays a certain role, but the total number of households residing in each region has a significant impact.



Year of construction / reconstruction	Estimated percentage of energy-poor households [%]		
1919 and earlier	32,84	±	4,05
From 1920 to 1945	25,55	±	3,06
From 1946 to 1970	19,22	±	3,08
From 1971 to 1980	17,56	±	3,06
From 1981 to 1990	14,54	±	3,48
From 1991 to 2000	12,09	±	2,92
From 2001 to 2010	9,58	±	2,51
From 2011 to 2015	4,02	±	3,00
2016 and later	0,62	±	0,94

Figure 11 - Estimated representation of energy poverty in each category: Age of Building

Figure 11 shows how probable it is that a household will be affected by energy poverty if it occupies a house that falls into the relevant category. The estimate of the distribution of households affected by energy poverty, based on the age of the dwelling they occupy, fully corresponds with the time since the last renovation of the property. Thus, the households most affected are those residing in older, unreconstructed buildings. These properties often have poorer insulation capabilities of the building envelope, leading to increased energy demand of the building.

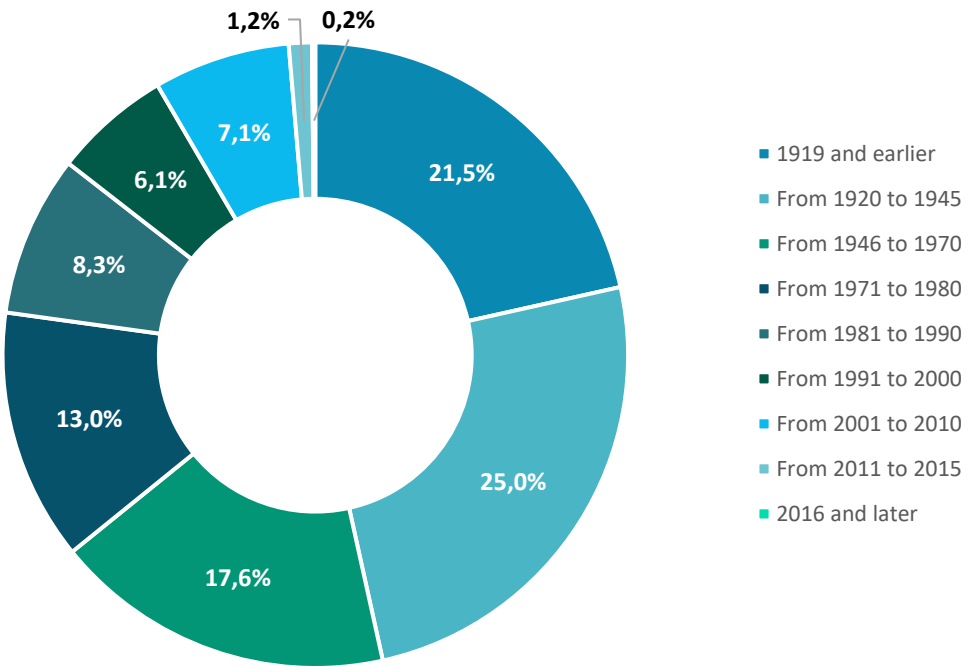


Figure 12 – Estimation of representation of energy poverty: Age of the building

The preceding graph depicts the distribution of households within the set of generated values across individual categories of dwelling age. The resulting values indicate that over 77% of households affected by energy poverty reside in buildings constructed in 1980 or earlier. This fact necessitates adapting the strategy and programme for reducing energy poverty. Therefore, the programme should primarily focus on the renovation of these houses and enhancing their thermal and physical properties.

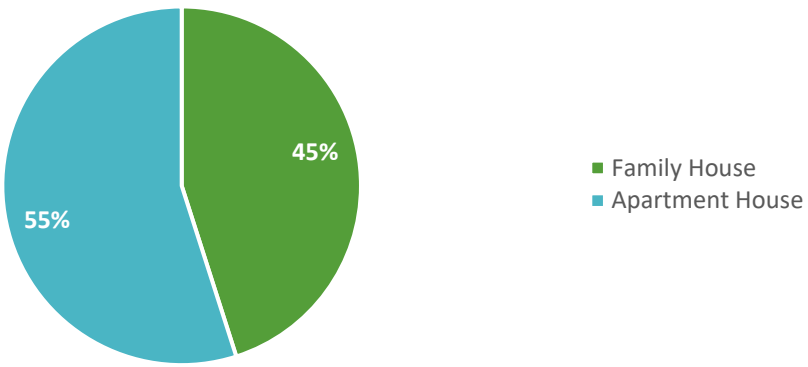


Figure 13 – Estimated representation of energy poverty by Type of the building

From the representative sample of households, which are represented by households generated by the created model, it can be shown that 45% of households affected by energy poverty live in single-family houses. For single-family houses, the probability of a household being affected by energy poverty is higher. However, due to more households

residing in apartment buildings in the Czech Republic, there are also more energy-poor households living in apartment buildings.

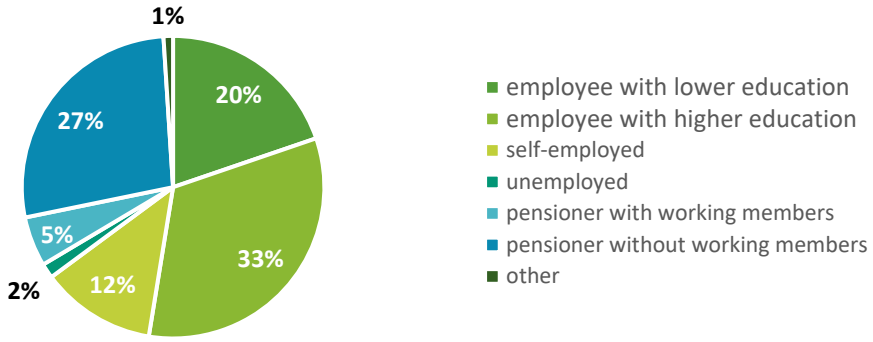


Figure 14 – Estimated representation of energy poverty by Head of Household

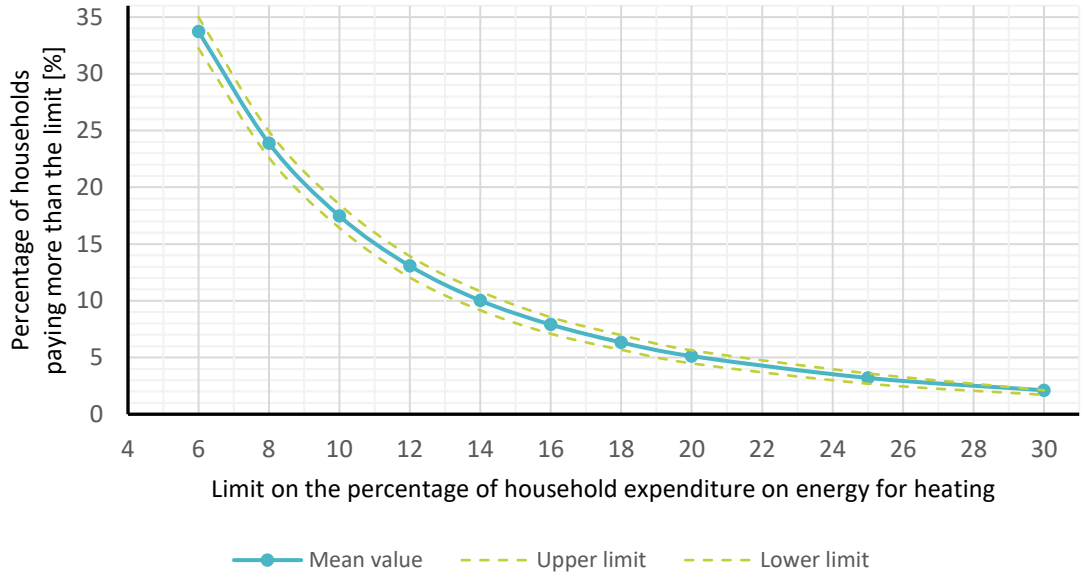
The previous Figure illustrates the distribution of households identified as energy-poor based on the employment status of the head of the household. This is an estimate of representation, so the percentages are heavily influenced by the number of households in each group. If a percentage probability is determined for each category individually, the following data is obtained. In Table 16, it is evident that more than employees, who were the majority group in Figure 14, households of retirees are at risk of energy poverty.

Table 16 – Estimated representation of energy poverty in each category: by Head of Household

Head of Household	Estimated percentage of energy-poor households [%]		
Employee with lower education	18,06	±	2,59
Pensioner	21,73	±	5,93

10.3.3 Sensitivity analysis of the energy poverty trend

Using sensitivity analysis, the sensitivity of the calculation to the established energy poverty threshold was examined. For the baseline calculation model, the threshold was set at 10% of household income spent on heating energy expenses. To provide a better overview and as a basis for decision-making regarding the threshold's determination or its inclusion in the energy poverty definition, a sensitivity analysis was conducted. The following calculations demonstrate how the model's outcome changes when the condition value is adjusted.



Limit on the percentage of household expenditure on energy for heating	Percentage of households paying more than the limit [%]
6%	33,73 ± 1,48
8%	23,89 ± 1,27
10%	17,47 ± 1,05
12%	13,07 ± 1,02
14%	10,02 ± 0,86
16%	7,90 ± 0,8
18%	6,33 ± 0,65
20%	5,12 ± 0,64
25%	3,20 ± 0,51
30%	2,11 ± 0,40

Figure 15 – Sensitivity analysis – dependence on a specified expenditure limit

The energy price is the second parameter strongly influencing the model outcomes, thus a sensitivity analysis of the results based on the percentage increase in energy costs was conducted. Other parameters remained unchanged. A household that spends an amount equal to or more than 10% of its income on energy expenses is considered an energy-poor household.

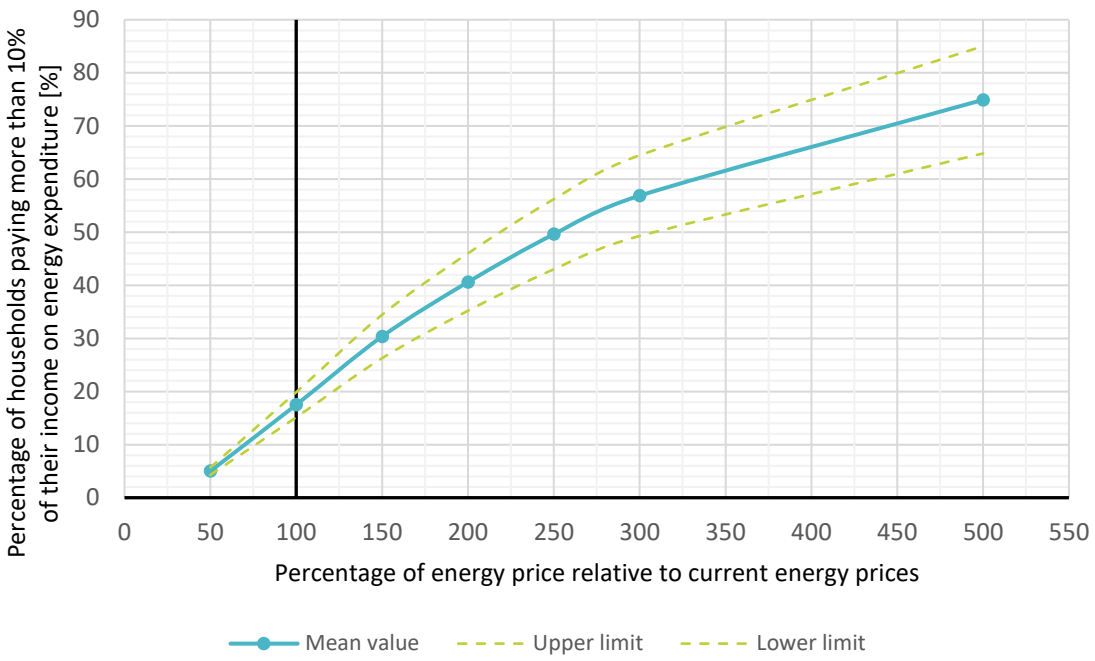


Figure 16 – Sensitivity analysis – dependence on a price level

Sensitivity analysis to energy price increase shows that the energy cost has a significant impact on the outcome of the model calculation. A 100% increase in energy price will raise the proportion of households classified as energy poor from 17% to 40% in this category. If the energy price increases by 200%, nearly 60% of households in the Czech Republic will fall into the selected household category, meaning they will allocate more than 10% of their incomes towards heating expenses.

10.3.4 Prediction of the evolution of the number of energy-poor households

The development prediction was estimated based on two main key factors, depending on the evolution of household energy costs and the progression of building renovations within the Czech housing fund. A review was conducted on the percentage increase in energy prices concerning the total number of households spending more than 10% of their income on building heating. A prediction of price development was established based on consumer price indices determined by the Czech Statistical Office.

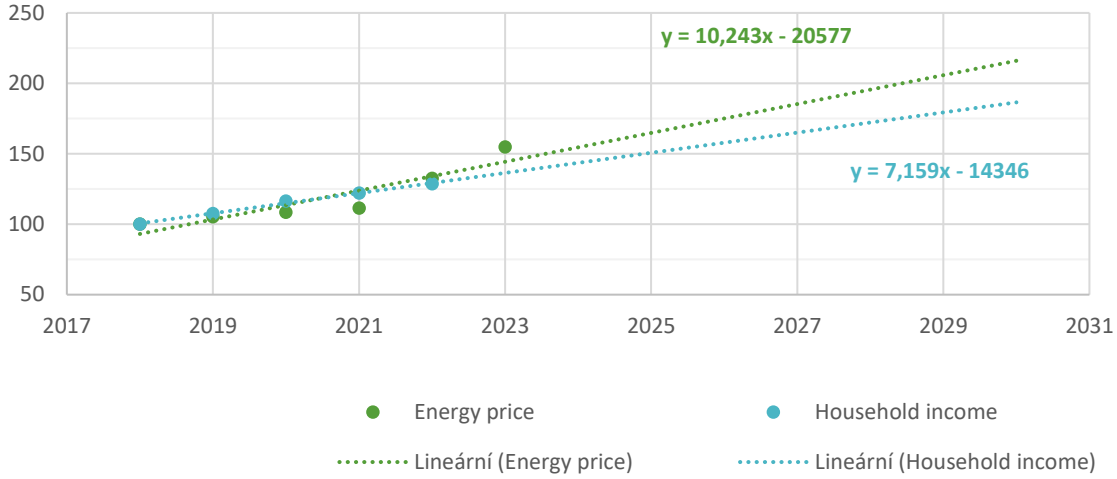


Figure 17 – Prediction of energy price

Source: Data – Czech Statistical Office, Prediction – calculation

When estimating the evolution of energy poverty in the year 2030, a price index of 216.29% was set. If only the price increase is considered, the projected representation of energy-poor households in the Czech Republic is 43.61%. This model situation would arise if there were no increase in household income. If an increase in household incomes is also considered, the number of households affected by energy poverty will increase. This is because the index of household income growth for the year 2030 is lower than the index of energy price growth. The index for price growth to 2030 was set as 186.77%. In both scenarios, the year 2018 is considered as the reference. When considering income growth in the calculation, in the year 2030, there will be 21.71% of households spending more than 10% of their incomes on heating expenses.

However, due to the anticipated developments in the housing sector, where a gradual reconstruction of residential buildings is expected, the calculation was extended with an additional parameter characterizing the rate of housing stock renovation.

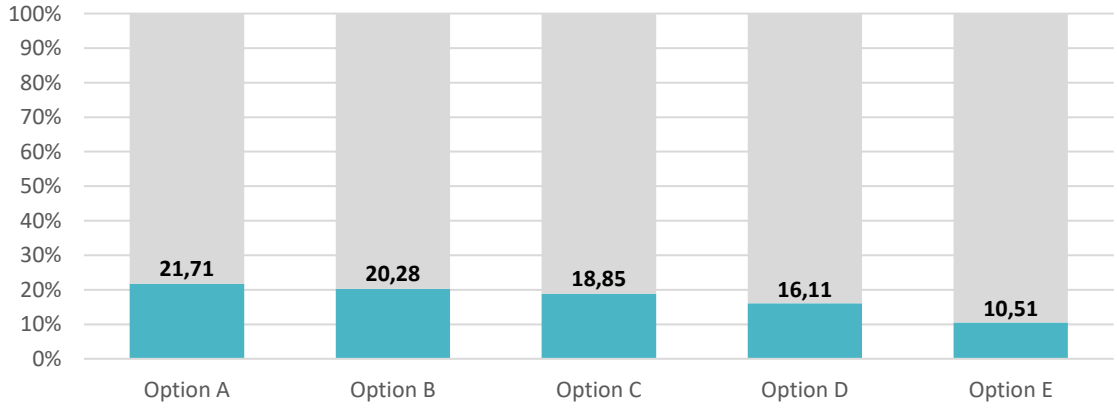


Figure 18 – Estimation of energy poor households in Year 2030 in Variant

- **Option A** represents the basic scenario characterizing the estimation of the development of energy-poor households in the year 2030. The model calculation considers an increase in energy prices by 216.29% compared to the year 2018 and an increase in household incomes by 186.77% compared to the year 2018. For this basic modelling scenario, the estimated proportion of energy-poor households is 21.71%.
- **Option B** is based on Option A but includes information about the transformation of the housing stock. The calculation assumes a 1% annual renovation of the housing stock. This renovation effort is evenly distributed among all properties.
- **Option C** is derived from Option B but assumes a housing stock renovation rate of 2% per year.
- **Option D** is based on Option A but considers a 1% annual renovation of selected properties. The calculation assumes that 80% of all renovated buildings are inhabited by households affected by energy poverty.
- **Option E** builds upon Option D but assumes a renovation rate of 2% per year.

From the previous model results, it is evident that within the current development characterized by Option A, there will be an increase in households spending more than 10% of their incomes on heating expenses by the year 2030. Even considering the current rate of housing stock renovation will not ensure a reduction in energy-poor households. The optimistic Option C, which assumes a renovation rate of up to 2%, leads to an increase in energy-poor households from 17.5% to 18.85%. To significantly reduce energy-poor households, it is necessary to support building renovations, especially for affected households, and promote a housing stock renovation rate in the Czech Republic of at least 2% per year.

10.3.5 Energy Saving Potential in Energy-Poor Household Buildings

The estimate of energy savings was conducted based on the created model. Energy savings were calculated for each household and its building. An estimation of household consumption was performed, and based on the existing building characteristics, a potential savings estimate was made. The estimation of savings was carried out exclusively for households identified as energy-poor households (those with heating expenses equal to or exceeding 10% of household income).

Because the modelled households are not identical to real ones (with a different number of households), a recalculation of savings in individual sets of households generated by the model was performed. The recalculation was done for energy savings per one household in the modelled set. Subsequently, a calculation of the potential real savings was conducted, based on the actual number of households in the Czech Republic.

The savings values were determined using a coefficient according to the age of the building. The potential achieved energy savings for individual building categories were estimated by expert assessment:

Table 17 – Indexes for estimating energy savings in buildings

Year of construction / reconstruction	Index of potential energy savings from total energy consumption in the building [-]
1919 and earlier	0.5
From 1920 to 1945	0.5
From 1946 to 1970	0.4
From 1971 to 1980	0.4
From 1981 to 1990	0.3
From 1991 to 2000	0.1
From 2001 to 2010	0.1
From 2011 to 2015	0.0
2016 and later	0.0

Based on the calculation, an estimate of the energy savings potential for energy-poor households in the Czech Republic was determined. The model calculation indicates that the **potential energy savings are 1,177.64 ± 190 kWh per household per year**. Assuming there are 4,813,103 (ENERGO 2021) households in the Czech Republic, the potential energy savings in buildings of energy-poor households' amount to 5,668.1 GWh per year (20.4 PJ per year). If considering the total heat demand for household heating to be 190.368 PJ (ENERGO 2021), this **savings represents approximately 10.7% of the energy consumption of all households for heating**.

11. Draft of programme for reducing energy poverty

The current situation of energy poverty in the Czech Republic has not been mapped out in detail yet. In addition, relevant information is missing, and it is necessary to rely on statistical data that are not sufficiently interlinked. This situation results in distortion that strongly influences the final outcome. Therefore, it is desirable to define the exact targets of the programme and to determine the target households in particular. Despite the inaccurate data, it is possible to draw inspiration from Western European programmes dealing with energy poverty, as the household situation in these countries resembles that in the Czech Republic.

A programme must be established that tackles energy poverty. This programme should offer solutions and help in the area of buildings and energy loss savings, which is the most preventable area. This area can achieve the greatest effect of financial savings of households.

11.1 Focus of the programme

The programme should focus on households most at risk of energy poverty. Of the 4.1 million occupied dwellings in the Czech Republic, an estimated 16% are potentially vulnerable households, resulting in approximately 650,000 households that need support to reduce energy poverty. Most at risk are low-income households, in particular:

- Senior households - a household in which only seniors live. There is no living person in the household who has income from employment;
- One-person households – a household in which one-person lives;
- Single-income households – a household in which one or more person live, but the household has only one income;
- Incomplete families – a household in which one adult lives with one or more children.

People living in family houses are more vulnerable. Unfortunately, from the existing information sources it is not possible to determine where which types of households live. However, it is possible to receive shares in the categories from the official statistics (CSO, 2016).

- Family houses (1,795,065 households, 43.7%);
- Apartment buildings (2,257,978 households, 55.0%);
- Other buildings (51,592 households, 1.3%).

The majority of energy losses are caused by heat leaking from heated rooms through the envelope and by high infiltration of cold air caused by a major leak and openings in the envelope. Other significant heat leakages can be found in distribution and heat conversion in the source, as older sources are less efficient, leading to heavy heat losses. It is therefore necessary for the programme to focus on building refurbishment, which will help increase their energy efficiency.

11.2 Methods of assistance for the programme

Some existing programmes and schemes in the Czech Republic already deal with these measures, so the limitation is not in the focus of the programmes, but in how subsidies are paid. Households affected by energy poverty should be enabled to improve their situation, as this would eliminate energy waste.

- The first possibility of this issue could be the payment of cash benefits in case of longer duration or severe freezing temperatures. This method of support is indeed effective and helps in emergencies, but its major shortcoming is its short-term nature. This kind of solution does not reflect future growth developments in energy prices and demands for housing.
- The next option could be a system of preferential loans, which is already used in the Panel 2013+ programme. Unfortunately, it is not aimed at households in family houses, which are the most vulnerable.
- The most effective solution, but also the most expensive, is the individual approach to households. The energy expert will identify leaks and suggest measures that will be implemented by a specialised company. Repayment to the investment funds will be gradually obtained from the energy savings. It will require a short payback period of measures; the optimal duration is less than 10 years. Such approach is similar to the Energy Performance Contracting method. The process of quality control and selection of architect and the construction company should be provided via energy efficiency fund. There are usually many players acting in the process of energy efficiency measures implementation: energy experts, architects, construction companies, banks, technical supervisors and energy suppliers, however, specifically for energy poor households, the governmental fund should take a maximum burden of the implementation. This solution does not burden the household economically. The household does not need finance for the initial investment in the measure. If the measure is well designed, the household will achieve energy and economic savings immediately after the action is taken. Higher economic savings will come when the investment is repaid.

The design of the programme must be a solution to the whole issue of energy poverty, not just its part or symptom. The programme must be incorporated into legislation. Cooperation with other legislative elements is essential (for example system of assistance in material need No. 111/2006 Coll). The programme must also co-operate with existing support programs for reducing energy consumption of buildings.

12. Proposal of appropriate strategy to reduce energy poverty

The following chapter brings together the important points that should be included in a strategy aimed at reducing energy poverty in the Czech Republic. This proposal outlines an appropriate strategy tailored to the specific context of the Czech Republic, taking into account the current societal and technological landscape. The goal of this strategy is to identify and recommend feasible measures that will contribute to effective and sustainable reduction of energy poverty. By examining the main factors and causes of energy poverty, as well as strategic approaches and interventions, such as improving energy efficiency in buildings, promoting renewable energy sources, providing financial assistance to vulnerable households, and implementing educational programs focused on energy efficiency, this proposal aims to provide a solid foundation for the development of an effective strategy that will lead to long-term reduction of energy poverty and improvement of living conditions for affected households.

12.1 Strategy framework

The content of this dissertation can serve as a basis for analysing the issue of energy poverty, which should also be a part of the strategy document. The analysis should include a review of existing measures and their impacts, with a focus on current support programs and an assessment of their benefits for households affected by energy poverty.

Based on the current development and the current situation, an analysis of possible future trends should be conducted. It is essential to explore the possibilities and opportunities that come with the inevitable construction reform. How it will affect households and how it will influence energy poverty should be examined. Pressures to use modern technologies in buildings, advanced insulation materials, and investments in energy production from local renewable sources have a positive impact on reducing energy needs in buildings. It is necessary to explore in greater depth how this positive development in construction will affect existing buildings and their occupants.

It is crucial to ensure that the current development does not have a negative impact on households affected by energy poverty or those on its brink, in terms of reduced access to energy, technologies, or materials.

12.1.1 Goals of Strategy

The primary task is to define the issue of energy poverty and anchor it in the current legislation. It is necessary to unify and clarify the definitions not only of energy poverty

itself but also of related issues. Based on the analysis of the current situation, a vision should be created to determine the direction of addressing the issue of energy poverty.

The strategy document should include possible solution proposals and, together with them, the assessment of their potential impact. The possibilities of the issue's development should be considered concerning the adopted measures in comparison to a zero variant. For estimating the development of the zero variant, the results of this dissertation can be used, which outline possibilities for the development of energy poverty.

Because energy poverty is primarily influenced by three main factors: low household income, low energy efficiency of buildings, and high energy prices, the strategy document needs to reflect these aspects. The global objectives of the strategy should be:

- Increasing energy efficiency of buildings - reducing the energy demand for building operations, lowering energy expenses;
- Evaluating household incomes - striving to balance incomes and expenses;
- Ensuring a reduction in energy prices and enhancing the availability of affordable energy for households, including local energy production.

12.1.2 Increasing the Energy Efficiency of buildings

One of the main factors contributing to energy poverty is the high burden on households due to inefficient buildings and heating systems. Many households, especially those with lower incomes, face high energy costs due to poor insulation, outdated heating systems, and insufficient utilization of renewable energy sources.

Increasing the energy efficiency of buildings can significantly reduce energy consumption in households and, consequently, energy costs. Investments in insulation, modernizing heating systems, replacing inefficient appliances with energy-efficient alternatives, and utilizing renewable energy sources can have a long-term positive impact on family budgets and reduce households' reliance on more expensive energy sources.

In addition to the financial benefits, increasing energy efficiency in buildings also has a positive impact on the environment. Reduced energy consumption leads to lower greenhouse gas emissions and less polluted air, contributing to climate protection and improving the quality of the environment for everyone.

To achieve a reduction in energy poverty through increasing the energy efficiency of buildings, several steps are crucial. These include providing financial incentives and grants to households with limited financial means, enabling them to undertake necessary adjustments and modernizations. It is also essential to offer technical support and advice on energy efficiency, ensuring that households are informed about the available options and benefits.

Education and awareness are also integral components, helping households understand the advantages and implement energy-saving measures. Collaboration with governmental and non-governmental organizations, energy companies, and the construction sector is also crucial for successfully implementing measures to enhance energy efficiency in buildings and reduce energy poverty.

Overall, it can be concluded that increasing the energy efficiency of buildings is a key factor in reducing energy poverty. It provides economic benefits to households, protects the environment, and contributes to sustainable development. To achieve these goals, the implementation of appropriate policies, support, and cooperation among various stakeholders is essential.

12.1.3 Evaluation of Household Incomes

Each household has several ways it can start reducing energy expenses and improve the financial aspect of its budget. Every household is unique, and therefore, it is not possible to provide a standardized guide for households in the Czech Republic. Firstly, it is necessary to evaluate the income and expenses of each household, especially from the perspective of energy costs.

Depending on the financial capabilities of the household, several general procedures and points can be suggested to reduce energy consumption and consequently lower energy expenses. However, each point must be adjusted according to the specific situation and financial possibilities of each household.

1) Replacement of the existing **lighting** with modern energy-efficient LED bulbs. These modern light fixtures have significantly lower energy consumption. As part of reducing energy consumption for lighting, it's not just about replacing the appliances themselves, but also about revising user behaviour. It is advisable to turn off lights when they are not needed or when leaving a room. Make the most of natural daylight whenever possible.
2) Energy savings can also be achieved in the case of **water consumption** and hot water usage. One of the key steps is to review the distribution systems and appliances, ensuring that water leakage does not occur when it's not desired. Keeping appliances in good condition not only prolongs their lifespan but also ensures better, fault-free water distribution within the property. Similarly, to lighting, behavioural changes by consumers can lead to energy savings in water usage. Efforts such as taking shorter showers, turning off running water while brushing teeth, etc., result in reduced water consumption and decreased energy demand for water heating. With the possibility of lower investments, consideration

can be given to installing energy-efficient devices, such as low-flow showers or low-flow faucets.

3) Sealing the building envelope and addressing gaps in openings and fenestrations is crucial. Older structures might experience issues not only with the thermal envelope of the building but also with **air infiltration**, which significantly affects a building's energy demand. Leaks in the building envelope allow warm interior air to escape and cold air to enter, resulting in heat loss and increased energy consumption for heating.
4) Ensuring proper, **adequate ventilation** without unnecessary energy loss. Improper ventilation can lead to heat loss from the building. If ventilation is too intense or uncontrolled, excessive air exchange can occur, leading to heat loss and energy waste from heating the incoming cold air. Issues can also arise with older ventilation systems; outdated or inefficient ventilation systems can be energy intensive. Inefficient fans, air filtration, or ventilation controls can elevate the energy consumption associated with operating these systems.
5) The next measures are related to appliances within the building. If **modern energy-efficient appliances** are utilized, it is possible to achieve a reduction in the energy demand for their operation. Energy-efficient appliances can help lower energy costs and thereby improve the financial situation of low-income households, but there are several factors that need to be taken into account. For households on a tight budget, the initial investment can be a barrier, which is generally higher compared to less efficient appliances, even though the overall economic efficiency could pay off, the higher initial investment can be a barrier.

The following measures are primarily focused on the modification of the building's heating system and building envelope. These measures are among the most important for reducing energy consumption, but at the same time, their financial demands are high, which is why they are listed at the end of this list.

1) A highly significant measure is to increase the energy efficiency of the building envelope, which includes **insulating building walls, roof** and possibly the floor, **replacing windows**, and other components. These actions can greatly assist in addressing energy poverty. By improving the building's energy envelope, heat loss from the building is reduced, and its energy efficiency is enhanced, resulting in a decreased heating demand. However, it is important to realize that the initial investment in improving the energy envelope can be high. Households experiencing energy poverty may encounter difficulties in financing these modifications. Therefore, it is crucial for financial support, grants, or programs to be available that would help them cover the costs of enhancing the building's energy envelope.

Additionally, other factors such as user habits and other socio-economic aspects must be considered to achieve a genuinely effective solution to energy poverty.

2) **Replacing the heat source** can be a significant measure in addressing energy poverty, especially when dealing with less efficient and costly heating systems. Modern heat sources such as condensing gas boilers, heat pumps, and solar systems often have higher efficiency compared to older heating systems. This means they consume less energy to achieve the same or even higher output, which can significantly reduce energy costs. These sources can prove to be economically advantageous in the long term as they have lower operating costs and require less maintenance. Financial support, grants, and energy efficiency support programs play an indispensable role in this case as well, given the high initial acquisition costs.
3) **Installation of renewable energy sources** (RES): such as solar panels, wind turbines, or other renewables, can reduce their dependence on more expensive energy sources. Energy-poor individuals can be vulnerable to price fluctuations and inadequate availability of conventional energy. RES can enhance their self-sufficiency and stability by enabling independent access to energy, especially in situations where obtaining energy from the central grid is difficult. However, it is important to note that successful integration of RES in addressing energy poverty requires a thorough analysis of local conditions, financial resources, and technical possibilities.

   The installation of RES can form the foundation for community projects, where people collaborate on the creation and management of renewable energy sources. These projects can strengthen community bonds and create opportunities for education and engagement.

12.2 Supporting the development and use of energy communities to reduce energy poverty

The average household consumption has been increasing in recent years, primarily due to higher demands for living comfort, leading to an increase in energy requirements. There is a development of local energy sources, which are becoming more accessible to households from both technical and financial perspectives.

One of the ways to assist households affected by energy poverty is community energy, which has the potential to reduce energy costs for end-users, including households impacted by energy poverty.

It is essential to recognize that energy poverty is closely linked to financial poverty, but solutions need to be sought using different tools. Since it is strongly related to the

energy-technical state of buildings, one of the possible solutions is to support the improvement of building energy efficiency, reduce unnecessary energy consumption, or promote local energy sources. Existing subsidy schemes are structured in a way that energy-poor households are unable to utilize them fully, as some eligible expenses are reimbursed only after implementing energy-saving measures.

National programs for social support may assist households in difficult situations and can be used for transitional periods, but they cannot be considered a solution to energy poverty. To address energy poverty, the root causes of high energy costs need to be examined, which may be related to either the poor energy-technical condition of buildings or oversized buildings. Existing support programs focused on building energy efficiency should be adjusted to better target energy poverty.

Another approach to addressing energy poverty could involve supporting social housing, ensuring affordable temporary housing for low-income households with reasonable energy costs.

Achieving a reduction in energy costs can be supported by local energy production, especially through Energy Communities (ECs). Properly set relationships within ECs can lead to reduced energy costs for their members. Establishing ECs with the involvement of municipalities and local authorities provides them with a tool to address local support for energy-poor households.

Finally, it is crucial not to underestimate the motivation of households not currently impacted by energy poverty but who may face increased energy costs due to future price developments. These households need to be motivated to take timely actions that will ensure sufficient energy consumption reduction in buildings or the adoption of energy production from cheaper sources.

12.3 Engaging energy flexibility in tackling energy poverty

Energy flexibility can play a crucial role in addressing energy poverty. Energy flexibility refers to the ability to adjust energy consumption based on supply and demand in the energy market. This flexibility can be utilized to reduce energy costs for households and enhance their access to cheaper and renewable energy sources.

Energy flexibility offers several benefits, including improved stability and reliability of the energy system, reduced greenhouse gas emissions, support for renewable energy development, optimization of investments and energy infrastructure costs, and the ability to adapt to future energy needs and demand changes.

The utilization of energy flexibility is expanding not only in large energy grids but also in households, where consumers are becoming active participants in the energy system.

Consumers can contribute to balancing energy demand and supply through smart management of their energy consumption and the use of new technologies such as energy storage batteries and intelligent appliance control.

Energy flexibility plays a key role in modern energy systems facing increasing energy demand and challenges related to renewable energy sources. Engaging energy-poor households in the energy flexibility system has the potential to reduce energy costs and improve energy efficiency for end-users while also contributing to the stability of the energy system.

The energy system deals with variability in energy production and consumption. For the proper functioning of the energy system, especially the electrical grid, it is crucial that energy supply to the grid and its withdrawal are balanced. Otherwise, power outages or damage to the grid may occur.

Renewable energy sources, such as wind farms and solar panels, are dependent on natural conditions and may exhibit fluctuations in their production. Energy flexibility enables the management of these fluctuations to ensure the stability and reliability of energy supply. Through flexible mechanisms, the system can quickly respond to changes in production and demand, minimize supply fluctuations, and maintain the energy grid in balance.

There are several fundamental ways connected to energy flexibility that can help address energy poverty. The following list represents the main approaches that need to be considered when devising a strategy to reduce energy poverty:

1) Variable energy tariffs present one option to motivate households to manage their energy consumption primarily during periods of abundance. Implementing variable tariffs allows households to consume energy during times of lower demand when prices are lower. This can reduce energy costs for households and improve their financial situation.
2) Supporting the development of modern grids, also known as Smart Grids, is another option to enable efficient energy supply management based on demand and supply. It is a way to better balance energy loads and utilize less stable renewable energy sources to the maximum extent possible. Utilizing cheaper renewable energy sources and their efficient use could lead to a reduction in energy costs and assist households in managing expenses.
3) Battery storage systems offer an opportunity to lower energy costs, as households can utilize batteries and storage systems to store energy from cheaper sources to consume when prices are higher. Employing energy storage systems allows for better control over energy expenses. However, the initial investment required for such systems may be a barrier for households affected by energy poverty. Creating

a suitable financing programme to assist with these investments while remaining financially sustainable for the state is crucial.

4) Timing and deferred efficient consumption can incentivize households to engage in energy-efficient practices and savings. For instance, households can defer appliance usage to periods of lower energy prices or use smart technologies to manage consumption.

The listed tools are only the basic ways of integrating energy flexibility into addressing energy poverty. The development of energy flexibility will bring further possibilities to reduce energy costs for households, but it is essential to consider the financial capabilities of households to ensure that they can participate in modern energy trends without burdening their finances.

12.4 Document of action/implementation plan

After completing the strategic document, it is important to proceed with creating a specific action plan. This plan serves as a key tool for achieving the set objectives and realizing the vision outlined in the strategy. Its purpose is to comprehensively describe the steps and activities through which the strategy will be executed.

The implementation plan should be based on mid-term goals that are derived from the long-term vision. These goals should be specific, measurable, achievable, relevant, and time-bound (SMART). The plan should reflect the overall direction that the organization aims to take while respecting the specific conditions and opportunities of the environment in which it operates.

The implementation plan itself should include a list of tasks necessary to fulfill the established goals. These tasks should be organized into a logical structure that allows for a clear overview of their execution. Each task should provide a detailed description of its implementation process and a measurable objective to be achieved. It's important to clarify who is responsible for each task and what resources (people, financial means, technology) are needed for its execution.

When formulating the implementation plan, it's crucial to ensure that the designated tasks are realistic and achievable. Each task should be feasible within the defined timeframe and supported by specific steps leading to its completion. Additionally, it's important to incorporate mechanisms for ongoing monitoring and evaluation of task fulfilment to promptly identify any deviations and take corrective actions.

An implementation plan for reducing energy poverty should encompass several key elements to ensure effective strategy execution:

12.4.1 Definition of action plan goals

Define specific goals for reducing energy poverty that will have measurable outcomes and a timeframe in which they will be achieved. These goals will serve as clear indicators of the action plan's success and will be the basis for its evaluation. The following list provides potential goals that can be set in an action plan for reducing energy poverty:

- **Reduce the number/percentage of households affected by energy poverty** – This goal is one of the key ones but is closely tied to the energy poverty reduction strategy document that should be created for the Czech Republic. This document should establish a Czech definition of energy poverty. Based on this definition, specific goals in the action plan can be developed to decrease the proportion of energy-poor households. One such goal could be to reduce the percentage of households living in energy poverty by 30% over the next 5 years. A measurable indicator would be the numerical or percentage decrease in energy-poor households.
- Another goal of the action plan could be to achieve **increased building efficiency** in the Czech Republic, focusing on building renovations and technologies used within them. The aim could be to improve building energy efficiency by 10% for a specified number of households within a defined timeframe. Since detailed data about the existing housing stock in the Czech Republic might not be available, it might be more advantageous to set a goal for the percentage renovation of the existing housing stock to achieve its renewal. A measurable indicator would be the reduction in energy consumption per unit area of a building for a specified number of buildings.
- Action plan goals don't necessarily have to focus solely on the reconstruction of specific buildings; they can also aim to increase the share of renewable energy sources in the energy mix to a predetermined percentage within a certain timeframe. For instance, increasing the proportion of renewable energy sources used for building heating to 30% over the next 5 years. Tracking the specific share of renewable energy sources utilized in buildings can be challenging, so it might be more feasible to use a measurable indicator like the overall energy mix of the Czech Republic or set a target number of buildings where a renewable energy source with a specified minimum utilization ratio for heating will be installed within a calendar year.
- As secondary goals, not primarily aimed at reducing energy poverty but considered as preventive measures to curb the expansion of energy-poor households, another goal could be to increase the number of people educated in building energy efficiency and energy management within buildings. For example, informing 1,000,000 people about the issue annually. This goal should spread awareness

among households and empower them to change behaviours within their means, thus reducing the risk of energy poverty. A measurable indicator would be the number of participants who receive the information.

The established quantitative goals of the action plan should be specific, measurable, and realistic. There must be continuous monitoring of their achievement to assess whether the desired results are being met. If necessary, the original plan should be reevaluated to ensure their attainment.

The crafted action plan document should not only include quantitative goals but also focus on qualitative goals. These qualitative goals aim to achieve changes, improvements, and impacts that are not easily measurable with specific numbers but can have a significant influence on the energy poverty situation:

- Changing household energy usage behaviour – The goal should be to encourage people to use energy more efficiently and sustainably. This could involve campaigns highlighting the benefits of energy conservation and offering practical advice for reducing energy consumption.
- Related to the previous point, another goal could be reducing dependence on fossil fuels. The focus should be on sustainability, energy security, and environmental protection. This could involve supporting investments in renewable energy sources, promoting local projects for biofuel or biomass production and utilization.
- The aim could be to improve the quality and well-being of life, targeting aspects such as mental well-being, health, and comfort for households affected by energy poverty. Implementation of mental health support programs and initiatives to enhance well-being in households experiencing energy poverty. Ensuring adequate lighting and heating in homes, contributing to improved comfort and quality of life.
- Qualitative goals might aim to strengthen cooperation among individuals and organizations within the community. This could involve organizing regular community meetings, forums, and events that encourage networking among community members. Creating an online platform or social network for communication and information sharing within the community.
- Supporting community energy initiatives and energy sharing can be a significant and relevant goal within an action plan to reduce energy poverty. Community energy focuses on involving and activating local communities in energy production, distribution, and consumption processes. Community energy support, in a way, combines all the previous points and has a positive impact, especially on developing local infrastructure, promoting renewable energy sources, strengthening community ties, educating households, and ultimately enhancing security and self-sufficiency.

12.4.2 Energy poverty analyses

The action plan should include analyses that provide a comprehensive view of the current energy situation, community needs, and opportunities. These analyses serve as the foundation for strategic decision-making and the formulation of specific measures. The content of this thesis includes a substantial portion of the analyses that the action plan should encompass. The action plan should primarily include the following analyses:

- **Energy Poverty Analysis** – Identification and quantification of households experiencing energy poverty.
- **Housing and Energy Infrastructure Analysis**
- **Renewable Energy Analysis** – Evaluation of the potential for utilizing renewable energy sources.
- **Financial Feasibility Analysis** – Assessment of financial resources and available funding.
- **Technical Feasibility Analysis**
- **Legal Regulations and Policy Analysis**

These analyses collectively contribute to a well-informed action plan, enabling effective strategies and targeted interventions to address energy poverty.

12.4.3 Creating a timeline

The timeline of the action plan should be realistic and structured in a way to ensure a gradual and effective progression towards achieving the set goals. Consideration of the timeframe is crucial so that the plan can be managed, and its progress evaluated regularly.

- Preparatory Phase - Conducting surveys and data collection, performing analyses, and identifying key factors contributing to this situation. Identification of relevant stakeholders. Formation of a project team consisting of experts.
- Planning and Goal Setting Phase - Setting quantitative and qualitative objectives. Formulating specific measures that will lead to achieving the objectives.
- Implementation Phase - Implementing measures to enhance the energy efficiency of buildings, installing more energy-efficient equipment, incorporating renewable energy sources. Introducing financial programs and tools to support households affected by energy poverty. Execution of educational programs focused on energy efficiency and sustainability.
- Monitoring and Evaluation - Monitoring the progress made in achieving the quantitative and qualitative objectives.
- Development and Expansion - Adapting the action plan based on new information, experiences, and community needs.

12.4.4 Defining responsibilities and roles

The action plan must include the assignment of responsible parties for each section of the action plan, its measures, and activities. Roles and responsibilities of stakeholders, including government organizations, local entities, non-profit organizations, etc., must be clearly defined.

12.4.5 Establishing continuous evaluation

The action plan must include mechanisms for ongoing monitoring and evaluation of the implementation progress. Define indicators that will measure the success of the plan and enable the early identification of potential issues.

As part of the monitoring, data collection should also be included. Data is collected primarily for two reasons. The first reason is the continuous assessment of the situation, measuring quantitative indicators related to energy poverty:

- Demographic data
- Data on energy consumption
- Data on prices, energy costs
- Household incomes and financial situations
- Data on housing stock condition

The second category of data that should be monitored as part of the monitoring process is data related to specific projects created to fulfil the goals of the action plan. Each project or measure within the action plan should be continuously monitored. It is monitored whether the set objectives are being achieved and whether the steps are in line with the plan.

A system of ongoing communication with households needs to be established, and feedback regarding the progress and effectiveness of the action plan should be obtained from them. This can be done through surveys, meetings, or online discussions.

12.4.6 Risk identification and establishment of milestones

It is highly important to identify potential risks associated with the implementation of the action plan. An action plan aiming to reduce energy poverty may encounter the following potential risks that could impact its success:

- **Lack of Financial Resources** - Insufficient financial resources can result in the slowdown or cessation of implementing action plan measures.
- **Low Household Interest** - Inadequate household support/interest can lead to reduced plan effectiveness. Proper communication is needed to stimulate

household interest, enhance their awareness, and ensure adequate utilization of offered programs.

- **Legislative Changes** - It is necessary to monitor changes in legislation pertaining to energy, energy use in buildings, or financing. New regulations or alterations in financing conditions can impact the costs and feasibility of action plan measures.
- **Ensuring Energy Infrastructure** - Inadequate development or adjustment of energy infrastructure (such as insufficient energy network capacity) can slow down measure implementation or lead to increased implementation costs.
- **Risk of Energy Savings Not Being Achieved** - It is important to meticulously design and subsequently monitor proposed measures. When measures are combined, they might influence each other, and outcomes might not meet expectations. Uncertainty about actual savings can influence the financial plan and return on investments.
- **Dependency on External Factors** - Energy and new technology prices can influence market trends and household interest in energy-saving measures.

For monitoring the progress of action plan implementation, checkpoints/key milestones are crucial. For each checkpoint, control criteria must be established, which must be met within a given timeframe for the checkpoint to be considered achieved. The criteria should be measurable and clearly defined.

Checkpoints will primarily stem from the established measurable objectives and measures of the action plan, as outlined in section 1) Definition of Action Plan Goals.

If it becomes evident that certain checkpoints or objectives have not been met, it is essential to respond swiftly and take corrective measures. This might involve modifying the plan, allocating additional resources, or restructuring projects.

12.4.7 Strategies for encouraging energy efficiency across various housing scenarios

In addressing energy efficiency in residential buildings, distinct housing scenarios present diverse challenges and motivations. Factors such as property ownership and occupancy status significantly influence individuals' willingness to embrace energy-saving measures. Here's an approach for encouraging energy savings tailored to each of these housing situations:

- **Property owner (lives in the building)** – It is quite easy to motivate property owners, especially well-off owners of a family house who have reasonable income.

It is advisable to create a programme for this group that will adequately inform about the benefits of energy-saving measures and, if appropriate, refer to other subsidy programs. A similar approach will hold for flat owners in apartment buildings. However, a question might arise to equally motivate all members of a buildings.

- **Property owner (rents out the property)** – The strongest motivation for this group is the increase of the property value due to, reduction of heating and operating costs of the building. It is desirable to increase motivation and willingness of these owners to invest into renovation and secure increased energy efficiency of the housing stock.
- **Tenants** – they do not live in their own apartment, so they should be motivated from the perspective of their expectations they have of the apartment. There is a need for greater awareness and dissemination of knowledge about energy efficiency in buildings. Increasing demand for efficient buildings will result in blurring of the market and increasing tendency to implement energy-related measures.

By tailoring energy-saving strategies to these distinct housing scenarios, we can promote more widespread adoption of energy-efficient practices in the residential sector.

13. Conclusion

The current measures adopted in the Czech Republic aimed at mitigating energy poverty, while commendable, have yet to receive the attention they truly warrant. A comprehensive model, encompassing both technological and economic facets, estimates that nearly 17% (for data 2021) of households in the country fall below the energy poverty threshold, a significant figure indeed. In light of this, it is imperative to establish strategic objectives in the realm of energy poverty. This entails the formulation of a national definition and the prompt development and adoption of a National Strategy to Address Energy Poverty in the Czech Republic. Subsequently, a set of national monitoring indicators, designed to assess energy poverty within the country, should be established in consonance with the national strategy. The critical indicators have been elucidated in distinct chapters.

This thesis holds a distinctive influence on the national strategy designed to tackle energy poverty. The proposal for implementing the strategy in the forthcoming years forms an integral part of this endeavour. To this end, the Ministry of Industry and Trade spearheads an interdepartmental task force dedicated to energy poverty concerns. These proactive measures are anticipated to elevate the recognition of energy poverty at the governmental level, independently addressing the issue of poverty itself. It is worth noting that an official national definition of energy poverty remains absent in the Czech Republic, although dialogues have been initiated within EU member states. This thesis is poised to contribute novel insights to both the national energy poverty alleviation programme and the national definition. Importantly, the steps proposed herein have applicability across several Eastern European nations at the international level, serving as a foundational framework for the implementation of national energy poverty reduction strategies.

While the Czech Republic boasts considerable experience with energy efficiency support programs, their predominant focus has been on curbing energy consumption rather than directly confronting the issue of energy poverty. Consequently, these programs predominantly serve as preventive measures against energy poverty within households. State-sponsored housing allowances and benefits play a pivotal role in this context, albeit limited to assisting in household budget equilibrium. Although relocation to more energy-efficient residences may resolve the situation for individual families, the overarching predicament of energy-inefficient housing remains unaddressed.

Long-term projections anticipate a surge in energy prices, potentially resulting in a rise in the number of energy-poor households. This work includes forecasts pertaining to the prospective evolution of energy-poor households' representation in the Czech Republic. Consequently, households and the national housing inventory must be suitably prepared for this impending scenario. Timely intervention holds the potential to conserve substantial

primary energy and enhance or sustain the living standards of households. Thus, an expansion of efforts to tackle energy poverty, alongside the introduction of programs dedicated to its reduction, should stand as a pivotal policy directive within the Czech Republic.

The resolution of energy poverty bears benefits not only for households but also for the state itself. The state has committed to achieving specific energy and environmental objectives by 2030 and 2050. The segment of energy-poor households represents a latent contributor to the realization of these objectives. Nonetheless, without governmental or third-party intervention, the full extent of potential savings, household energy cost alleviation, and the associated energy-saving potential cannot be harnessed. The proactive alleviation of energy poverty also stands to fortify the state's energy security and reduce its reliance on energy imports.

13.1 Policy implications

This thesis has a specific impact on the national strategy to tackle energy poverty and should serve as a basis for its implementation. The Ministry of Industry and Trade, therefore, leads an inter-ministerial panel on energy poverty issues. These initiatives should lead to addressing energy poverty at the government level, independently of the poverty issue. The country still lacks an official national definition of energy poverty. However, discussions on the definition have been initiated in EU countries. This work should provide new information for both the national strategy to address energy poverty and the national definition. At the international level, the proposed steps are applicable in many Eastern European countries.

13.2 Important design points of the energy poverty reduction strategy

For the sake of the program´s efficiency, it is necessary to determine its focus but also design its appropriate use in areas where it is really needed. First, it is necessary to determine the target groups of the proposed programme and to choose the right form. In terms of energy efficiency, it is necessary to focus not only on the thermal envelope of the building, but also on other systems that have an impact on energy consumption. These are the main points that should be addressed by energy policy:

- Efficiency of the building envelope;
- Efficiency of technical equipment of buildings;
- Use of primary energy sources;
- Support the development of renewable energy sources;

- Legislative support for energy communities and household involvement in energy flexibility;
- Quality of the environment.

Support programs and legislation should also address the issues that may arise upon the change of the global energy market. Energy prices are rising, and so is household spending. This effect is reinforced by the growth of households affected by energy poverty.

13.3 Answering the research questions raised

At the commencement of the dissertation, research questions were delineated, for which corresponding resolutions were sought throughout the course of analysis. Comprehensive elucidation pertaining to each individual query and thematic domain is extensively expounded upon within the textual context. Subsequent sections offer a succinct compilation of the findings in response to the designated questions.

How to reduce energy poverty in the Czech Republic and how to help households already affected by energy poverty?

The thesis encompasses an assessment of current subsidy programs pertaining to the reduction of household energy costs, the enhancement of building energy efficiency, and the provision of support to economically disadvantaged households. These assistance programs have undergone evaluation, with a specific focus on their effectiveness in alleviating energy poverty. Given that none of the existing programs primarily prioritize addressing energy poverty to a degree that would qualify them as entirely beneficial, a new programme concept aimed at mitigating energy poverty has been put forward (Chapter 11).

A pivotal outcome of the dissertation is the formulation of a preliminary strategy for the mitigation of energy poverty. The proposal (Chapter 12) outlines crucial components that this strategy should encompass and furnishes illustrative examples of an appropriate strategy, customized to the unique circumstances of the Czech Republic. The development of this strategy draft takes into account the existing social and technological environment. The study also identifies measures that will play a pivotal role in achieving an efficient and enduring reduction of energy poverty.

What are the impacts of energy poverty on the household and the state?

Energy poverty exerts a substantial impact on households, with one of its prominent effects being a severe economic burden. Households in the Czech Republic grappling with energy poverty allocate a significant proportion of their income toward energy expenses, primarily for heating purposes. These expenditures severely curtail their capacity to invest in

enhancing their living conditions, and, in some cases, compel them to compromise on their quality of life and thermal comfort within their homes. Inadequate heating in their dwellings can lead to the risk of mold proliferation, structural deterioration, or heightened health hazards, especially when coupled with insufficient and fluctuating indoor temperatures. In sum, energy poverty detrimentally affects overall quality of life, precipitating stress, uncertainty, and a decline in living standards due to limited access to energy resources.

Part of the dissertation work involved evaluating the energy-saving potential within households affected by energy poverty. The calculation was conducted using a created model for simulating Czech households. From the model-based calculation, it is evident that the energy-saving potential amounts to 1,177.64 ± 190 kWh per household per year. This saving represents approximately 10.7% of the energy consumption of all households for heating (20.4PJ per year). Based on these calculations, energy-poor households represent a relatively significant area in which energy savings can be achieved, contributing to the fulfilment of goals set by the EU and the Czech Republic. Households in this category are unable to independently alter the energy demand of their dwellings, making it necessary for assistance to come from the government or other institutions to harness the potential for achieving savings.

What is the state of energy poverty in the Czech Republic and what households are affected by energy poverty?

A survey of households was conducted primarily based on statistical data related to households, housing stock, and energy consumption (Chapter 6). Based on the collected data, two models were constructed to aid in characterizing energy poverty in the Czech Republic (Chapters 8 and 9). These models depict the distribution of energy poverty across regions of the Czech Republic, among household categories, and based on building characteristics. According to the model, it has been determined that there are 731,600 to 950,100 households in the Czech Republic affected by energy poverty.

Is energy poverty of the same type in the Czech Republic as in other countries?

Based on the conducted survey, approaches to energy poverty were compared in the Czech Republic and other EU countries, especially in the United Kingdom, where there is a wealth of experience in addressing this issue. According to the gathered data, it can be observed that energy poverty in Western countries, including the Czech Republic, is primarily based on three factors: low household income, low energy efficiency of buildings, and high energy prices. The possibility of energy poverty caused by technological or distributional factors leading to energy unavailability can be excluded (apart from a few cases in isolated locations, solitary houses in mountains and forests). However, the primary issue of energy

poverty in the Czech Republic is caused by the mentioned three factors. Assistance in addressing the issue of energy poverty must also focus on these factors.

What is the impact of existing grant programs?

Part of the work also includes the evaluation of the existing subsidy programs in the Czech Republic that are relevant to the given issue (Chapter 4.5). Their focus and benefits have been assessed. Subsidy programs targeting energy efficiency in buildings have the right impact, but their limitation lies in low or no utilization by households affected by energy poverty. Particularly, there is an issue with financing, which is addressed by obtaining financial resources retrospectively after implementing energy-saving measures. Households affected by energy poverty do not have the opportunity to make use of these subsidy programs. Their financial situation also prevents them from utilizing banking services such as loans and credit. A new programme from 2023, the updated "Nová zelená úsporám" (New Green for Savings) program, introduced the possibility of using financial resources for partial building reconstruction. This represents a shift where utilization is possible even by energetically poor households, but the solution is not comprehensive. Therefore, partial renovation of the building only partially reduces energy costs. Moreover, there is a risk of encountering issues when using financial resources for window replacement (the most likely utilization due to the amount of funds). Partial building renovation can lead to moisture accumulation, poor ventilation, mold growth, and degradation of building structures.

What measures are appropriate against energy poverty?

One of the key triggers of energy poverty is the poor thermal-technical condition of buildings. It is essential to support investments in improving the energy efficiency of the housing stock in the Czech Republic. Primarily, this will lead to energy savings and associated expenditures, but it will also contribute to European energy-saving goals. A detailed evaluation of various subsidy programs is part of this work. It is necessary not only to provide financial resources for building renovations but also to focus on education. Educating households about efficient energy use, proper heating and cooling, and reducing energy waste can help lower their energy consumption and, consequently, costs.

Social assistance in the Czech Republic works very well and can provide aid to households in need. However, addressing energy poverty requires ensuring more lasting changes, primarily related to housing quality and energy needs.

What benefits can energy savings and expenditure have for households?

The purpose of assisting households affected by energy poverty is to empower them to make lasting changes. If only partial assistance, such as social support or reduced energy

prices, is provided, the situation may deteriorate in the future. A more sustainable solution is needed, based on three pillars: household incomes, energy needs, and energy prices. From the perspective of government or other institutions, the focus should primarily be on reducing the energy needs of buildings and lowering the prices paid for energy.

Detailed benefits are outlined in Chapter 12. Among the main benefits for households is the reduction of energy expenses. However, building renovations also come with other advantages, such as improving thermal comfort, enhancing quality of life, reducing the risk of cold-related illnesses or issues caused by moisture and mold. Proper assistance can contribute to greater social stability and help households at risk of social exclusion. Investments in energy efficiency can also mean better living conditions, with more modern and efficient heating and cooling systems, potentially increasing the value of the property.

What benefits can energy savings and expenditure have for the state?

Reducing energy poverty in the Czech Republic has benefits not only for the households that receive assistance, but also for the state. Reducing energy poverty:

- It can reduce the state's dependence on energy imports, thereby enhancing energy security. Lowering energy demand in buildings ensures a reduction in the need for energy that must be produced or imported from abroad in the Czech Republic. Alongside reduced energy consumption, emissions of greenhouse gases and other pollutants released during energy production are lowered, positively impacting the environment and aiding the state in meeting its environmental goals. The calculation of potential energy savings in the area of energy poverty in the Czech Republic has been determined within this work (Chapter 9).
- It can support modern technologies and revitalize the construction market. More efficient energy use in households can yield economic advantages, such as reducing overall energy costs and stimulating the economy through investments in energy-efficient technologies.
- It can help decrease the incidence of illnesses related to inadequate heating or cooling, such as respiratory problems or issues caused by mold. This can, in turn, reduce healthcare costs, contributing to the sustainability of the healthcare system.
- It is also in line with the principles of social responsibility for the state. Reducing energy poverty can contribute to greater social stability. When people have better living conditions and are not subject to extreme financial stress due to energy costs, they may be less susceptible to social exclusion or unrest.

13.3.1 Proposal of energy policy for energy poverty reduction

Energy poverty has two basic forms that differ in energy accessibility. The first form is the unavailability of energy sources. This form of energy poverty concerns predominantly households in less developed countries.

The second form of energy poverty can threaten EU households as it is not caused by energy inaccessibility but occurs due to the lack of available funds to cover the energy consumption of a building.

In recent years, household energy demand has grown, due to the increase of the comfort level that has an impact on energy consumption. The number of appliances and devices that are required in an object/building? is growing. A higher level of comfort and quality of the environment is required, such as air quality monitoring and conditioning (temperature, humidity). To meet all these requirements, it is necessary to pay higher energy costs.

A programme to reduce energy poverty should have the same goals, but attention should be paid to the form of the programme and its availability. Some subsidy programs are inaccessible to households affected by energy poverty. New Green Savings, a grant scheme of the Czech Republic, is an example of this case.

13.4 Challenges associated with further energy sector development

The energy sector is slowly starting to change, and the trends that will shape further energy development and solutions are evolving. There is a shift away from emphasizing centralized energy sources, with a focus on supporting local (especially renewable) energy sources. One of the tools that this effort brings is the concept of energy communities. Energy communities provide local municipalities with a means to assist energy-poor households in addressing their situation. Primarily, energy communities can help achieve lower energy prices. In combination with support for building energy efficiency and deep renovations, this is a way to significantly reduce the number of energy-poor households in the Czech Republic. However, it is essential to be cautious to avoid excluding certain households from this trend and ensure they have the opportunity to participate.

Alongside the development of renewable energy sources, the topic of energy flexibility is also emerging. Renewable energy sources have unstable energy supplies, and it will be increasingly necessary to address their fluctuations in supply. One of the solutions is the development of locally produced energy storage in Energy Storage and the development of flexibility trading. Flexibility trading should again be a new tool that will, in the future, enable reducing energy costs for end-users, including households. There is significant potential for energy savings, but also a substantial risk of excluding some households from

participating in the process. Households that are not part of the system may eventually face increased energy prices to the extent that they cannot use it as needed or afford it.

Next Steps in Addressing Energy Poverty

There is a pressing need to further deeper into the advanced realms of energy poverty research, with a specific emphasis on the prospects and advantages offered by energy communities and an analysis of energy flexibility. The upcoming sections will explore how these novel approaches can significantly contribute to the reduction of energy poverty in households, enhance energy utilization efficiency, and mitigate the risks associated with this evolving landscape.

Energy Communities

In the context of energy sector evolution, attention must be directed towards the concept of energy communities, which are poised to become an integral part of the energy landscape in the Czech Republic. It is imperative to ascertain their potential benefits for energy-deprived households. Subsequent research should investigate methods to leverage energy communities for cost reduction in energy and the augmentation of building energy efficiency. This topic is closely linked to the issue of comprehensive building renovations and how they can assist households in escaping energy poverty.

Energy Flexibility

Another emerging trend with significant implications for household energy costs is Energy Flexibility, closely tied to the increasing utilization of renewable energy sources. The examination of energy flexibility and its impact on energy poverty is essential, particularly as renewable energy sources gain prominence and influence the stability of energy supply. Emphasis should be placed on various approaches to harness energy flexibility for lowering energy expenses for households, alongside the scrutiny of associated risks.

Evaluating Benefits and Risks

It is crucial to assess the benefits and risks associated with the adoption of energy communities and energy flexibility as means to tackle energy poverty. The research should explore how these measures can affect energy accessibility and costs for different household types. Simultaneously, strategies for minimizing the risks tied to these novel energy concepts need to be devised.

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Appendix A - Source code sample of the model

The following source code demonstrates the principle of generating a set of households, which are subsequently evaluated based on specified criteria. Individual household parameters are added based on probabilities derived from previously generated values.

```
private void GenerateSets()
{
  // Set the number of households in the set
  int PocetVSade = 45000;
  // Set the number of sets
  int PocetSad = 100;
  // Generate based on variables number of households and sets
  for (int i = PocetSad; i > 0; i--)
  {
    SadaDomacnosti S = new SadaDomacnosti();
    for (int ii = PocetVSade; ii > 0; ii--)
    {
      // Create a new household
      Domacnost D = new Domacnost();
      D.Title = "D_" + i.ToString();
      // Based on probability, assign the household to a region
      D.Kraj = Kraj.Kraje[Kraj.GenerovatIDKraje()];
      // Based on the probability and the region parameter, assign the household the
      property Head of Household
      D.PostaveniOsoby =
      PostaveniOsoby.PostaveniOsobyList[PostaveniOsoby.GenerovatID(D.Kraj)];
      // Based on the probability and the region and head of household parameter, assign
      the household property number of members
      D.PocetOsob = PocetOsob.GenerovatPocetOsob(D.Kraj, D.PostaveniOsoby);
      // Based on probability and number of persons, assign the household to an income
      group
      D.SkupinaPrijmu =
      SkupinaPrijmu.SkupinyPrijmu[SkupinaPrijmu.GenerovatID(D.PocetOsob)];
      // Based on the probability, number of persons and income group, set the household's
      monthly income
      D.MesicniPrijmyDomacnosti =
      SkupinaPrijmu.GenerovatPrijemDomacnosti(D.PocetOsob.PocetCelkem,
      D.SkupinaPrijmu);
      // Based on probability, region and Head of Household, assign the building type
      D.TypObjektu = TypObjektu.TypyObjektu[TypObjektu.GenerovatID(D.Kraj,
      D.PostaveniOsoby)];
      // Based on the probability and the region sets the age of the building
      D.StariObjektu = StariObjektu.StariObjektuList[StariObjektu.GenerovaID(D.Kraj)];
      // Based on the probability and variables, assign the heating method of the building
```

```
    D.ZpusobVytapeni =
    ZpusobVytapeni.ZpusobVytapeniList[ZpusobVytapeni.GenerovaID(D.Kraj,
    D.TypObjektu, D.PostaveniOsoby)];
    // Based on the probability and the number of people, determine the size (number of
    rooms) of the apartment
    D.VelikostBytu =
    VelikostBytu.VelikostBytuList[VelikostBytu.GenerovatID(D.PocetOsob)];
    // Based on the probability and the number of rooms, determine the area of the
    apartment
    D.PlochaBytu = VelikostBytu.GenerovatVelikostBytu(D.VelikostBytu);
    // Based on the probability and age of the building, the type of building and the area
    of the apartment, determine the heat consumption for heating
    D.PotrebaTeplaVytapeniObjektu =
    PotrebaTeplaVytapeni.GenerovatPotrebuTeplaNaVytapeni(D.StariObjektu,
    D.TypObjektu) * D.PlochaBytu;
    // Determine the heating price based on the heating method
    D.CenaVytapeni = CenaVytapeni.GenerovatCenuVytapeni(D.ZpusobVytapeni);
    // Based on the heat demand and the heating price, determine the heating
    expenditure
    D.VydajeVytapeni = D.CenaVytapeni * D.PotrebaTeplaVytapeniObjektu / 1000;

    // Determine the ratio between heating expenditure and household income
    D.PomerVydajeVytapeni = ((double)D.VydajeVytapeni / (D.MesicniPrijmyDomacnosti *
    12)) * 100;
    // save the household to the database of Households in the set
    S.Sada.Add(D);
   }
   // save the set to the database of sets
   SadaDomacnosti.Sady.Add(S);
  }
}
```

Appendix B - Selected publications of the author on the topic of the dissertation

Karásek, J.; Pojar, J., **Programme to reduce energy poverty in the Czech Republic,** Energy Policy. 2018, Volume 115 131-137. ISSN 0301-4215

Pojar, J.; Karásek, J., **Energetická chudoba v ČR**, All for Power. 2020, (2/2020), ISSN 1802-8535.

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Kvasnica, J.; Karásek, J.; Pojar, J.; Bačovský, M.; Medová, L., **Moderní přístupy v ekonomice energetiky budov**, Praha: Czech Technical University in Prague, 2023. ISBN 978-80-01-07109-0.

Pojar, J.; Kvasnica, J., **UPSCALING ENERGY EFFICIENCY VIA ENERGY COMMUNITIES**, In: Challenges for University - Industry Collaboration - a Stakeholder View. Praha: The International Institute of Social and Economic Sciences, 2021. p. 73-86. 12th. ISSN 2570-6543. ISBN 978-80-7668-005-0.

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CULTURAL HERITAGE, International Journal of Economic Sciences. 2022, XI(2), 163-177. ISSN 1804-9796.

Macek, D.; Schneiderová Heralová, R.; Hromada, E.; Střelcová, I.; Brožová, L.; Vitásek, S.; Pojar, J.; Bouška, R., **Cost Optimization for Renovation and Maintenance of Cultural Heritage Objects, In: Central Europe towards Sustainable Building (CESB19)**. Bristol: IOP Publishing Ltd, 2019. IOP Conference Series:Earth and Environmental Science. vol. 290. ISSN 1755-1307.

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Macek, D.; Schneiderová Heralová, R.; Hromada, E.; Vitásek, S.; Střelcová, I.; Brožová, L.; Pojar, J., **A tool for Developing a Plan for the Renovation and Remediation of Cultural Heritage Buildings,** In: Acta Polytechnica CTU Proceedings. Praha: CTU. University Centre of Energy Efficient Buildings, 2022. vol. Vol. 38. ISSN 2336-5382. ISBN 978-80-01-07096-3.

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