Czech Technical University in Prague

Faculty of Civil Engineering

Department of Construction Management and Economics

Economic Evaluation of Energy Efficiency Policies in Buildings

Thesis submitted for promotion to associate professorship

March 2019

Ing. Jiří Karásek, Ph.D.

Table of Content

List of Abbreviations

AAU	Assign Amount Units
AB	Apartment Building
CDM	Clean Development Mechanism
CEN	European Committee for Standardization
DG Ener	Directorate General for Energy
DH	District Heating
EBRD	European Bank for Reconstruction and Development
EE	Energy Efficiency
EED	Energy Efficiency Directive
EPBD 1	Directive on the Energy Performance of Buildings (2002/91/EC)
EPBD 2	Directive on the Energy Performance of Buildings (recast)
EPBD 3	Directive on the Energy Performance of Buildings (second recast)
EPC	Energy Performance Contracting
ESCO	Energy Service Company
ESIB	Energy Saving Initiative in the Building Sector in Eastern Europe and the Central Asian Countries
EU	European Union
FH	Family House
GDP	Gross Domestic Product
GHG	Green House Gas
GI	Greening ratio indicator
HOA	Home owners association
IBRD	Investment Bank for Reconstruction and Development
IEE	Intelligent Energy Europe programme
IET	International Emission Trading
IRR	Internal Rate of Return
ISO	Organization for Standardization
JEL	Journal od Economic Literature
JI	Joint Implementation
MMR	Ministry of Regional Development
MS	Member States
MSC2010	2010 Mathematics Subject Classification
NGO	Non-Governmental Organization
NPV	Nett Present Value

OP	Operational Programme
PP	Payback Period indicator
RES	Renewable Energy Sources
RES	Renewable Energy Sources
SEAP	Sustainable Energy Action Plan
SEF	State Environmental Fund
SFRB	State Housing Development Fund
UN	United Nations
UNDP	United Nations Development Programme
VAT	Value Added Tax

Foreword

The research focused on economic evaluation of energy efficiency in buildings started in 2009 during my work at the State Environmental Fund of the Czech Republic and continued throughout the research performed at the Czech Technical University, and SEVEn, the Energy Efficiency Centre.

The work was further developed in three on demand studies carried out for the European Commission in 2013 and 2016 (Energy Saving Initiative in the Building Sector in Eastern Europe and the Central Asian Countries – ESIB, Selecting Indicators to measure energy poverty and EU Building Stock Observatory). Furthermore, relevant studies were carried out for the Ministry of Industry and Trade, Ministry of Regional Development, and The State Environmental Fund of the Czech Republic.

The studies led to the publication of the key results published mainly in Energy Policy journal and WIRES Energy and Environment journal. Such already published papers are the main source of the thesis. The scientific papers are presented via case studies in chapters 5 - 8. Since most of the works I have published in this field were written in English, I decided to submit the thesis in English to keep the international approach to the topic. I do believe will not cause any confusion to the reader and the thesis will be readable to a broader audience.

Acknowledgement

When I decided to write a short acknowledgement, I started to think about all the people who helped me in writing about Energy Efficiency policy evaluation. After a while, I was shocked. I found out how huge the group of people is. To keep the length of the text acceptable I did not personalize this acknowledgement. However, I hope they will find themselves in the following sentences.

I would like to express my gratitude to my university tutors opening the door to the Sustainable Development and Energy Efficiency topics. Followed by them, I met university people encouraging me in submission of this thesis and making conditions to be my work at the university feasible and pleasant. I would like to mention group of my former or current colleagues working in governmental institutions and consultancy, who are writing scientific papers and studies often without any reward, just because of their enthusiasm and love for energy efficiency. It is also worth to mention plenty of my European friends from H2020 projects and my English corrector, who brought the international dimension and experience to my work. Finally, I have to express my gratitude to my patient family supporting me every day, reading and commenting all my texts and most of them to my wife.

Abstract

As many countries, the Czech Republic joined the efforts to reduce energy consumption and greenhouse gas emissions within the framework of the Paris Conference commitment and EU targets. The national targets, based primarily on adaption of the EU targets towards 2020 and 2030, bring a critical need for evaluation of energy efficiency policies on different levels, starting from the governmental level and leading to the individual energy efficiency projects. The thesis describes main approaches used in economic evaluation of the general policies via energy efficiency (EE) and renewable energy sources (RES) programmes including studying their impact and recommendations for improvement.

The key goal of this thesis was to analyze and evaluate energy efficiency policies in the Czech Republic mostly from the economic point of view. Basic evaluation was performed according to the selected indicators, covering abatement costs, greening ratio, energy poverty level, payback period, and subsidy share of investment costs. The primary data for calculating indicators originated from the database of the supporting schemes, the author´s own data on achieved energy savings in individual projects, costs for the EE measures and high number of interviews conducted with the building owners.

The main method consists in the comparison of various approaches used for determining the costs for energy efficiency measures and calculation of primary and final energy consumption. The thesis describes a full range of energy efficiency measures and renewable sources installations. The method was applied on the main types of new and existing buildings covering the national building stock of the Czech Republic.

As a result, the economic evaluation of selected energy efficiency policies in buildings is presented, mainly Green Investment Scheme, current energy poverty policies and the national cost optimum approach. The thesis specifically includes recommendations on improvement of the energy efficiency policies in the Czech Republic.

Keywords: Energy Efficiency policies, economic evaluation, buildings, cost optimum, energy poverty.

Essential definitions

To have a common understanding of the essential terms used in the thesis, essential definitions in the field of energy, energy efficiency and economic evaluation are introduced in this chapter.

Energy efficiency means the ratio of output of performance, service, goods or energy to input of energy. The most common unit of energy efficiency is kWh/(m^2.y) (EP, 2012)

Energy performance of a building means the calculated or measured amount of energy needed to meet the energy demand associated with a typical use of the building, which includes, inter alia, energy used for heating, cooling, ventilation, hot water and lighting. (EP, 2010)

Energy savings means an amount of saved energy determined by measuring and/or estimating consumption before and after implementation of an energy efficiency improvement measure, whilst ensuring normalization for external conditions that affect energy consumption. (EP, 2012)

Energy performance contracting means a contractual arrangement between the beneficiary and the provider of an energy efficiency improvement measure, verified and monitored during the whole term of the contract, where investments (work, supply or service) in that measure are paid for in relation to a contractually agreed level of energy efficiency improvement or other agreed energy performance criteria, such as financial savings. (EP, 2012)

Nearly zero-energy building means a building that has a very high energy performance. The nearly zero or a very low amount of energy required should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby. (EP, 2010)

Cost-optimal level means the energy performance level which leads to the lowest cost during the estimated economic lifecycle. (EP, 2010)

Energy poverty is defined as a situation when a household cannot afford household energy services at acceptable cost. (EP, 2010)

1 Introduction

Energy efficiency together with an increasing share of renewable energy sources (RES) has become one of the crucial topics in the sustainable development on the global level. Starting with the oil crisis in 1970s the importance of energy efficiency has gradually increased. On the national level, the standard ČSN 73 05 40 (ČSN 73 0540-2, 2011) on thermal protection of buildings was a breaking document describing a full range of requirements on the building envelope and energy systems. The requirements underwent adjustment and reinforcement several times before they acquired the current form covering recommended values for passive houses as well. In parallel, the first law on energy management was introduced (Act No. 406/2000 Coll., 2000), bringing one of the first forms of energy audit in Europe and later also the Energy performance certificate in its current form. In order to strengthen the impact of the energy policy, the Czech Energy Agency was founded and the State Energy Policy was regularly updated. The first National Energy Efficiency Action Plan bringing the potential of comparison of energy policies was adopted in 2004 (MPO, 2017). All these activities led to the introduction of supporting schemes for energy efficiency projects including energy audit, investment subsidy and other financial instruments. Such a large scope of activities was supported by economic evaluation of the project alternatives in the preparation phase and economic evaluation of the project itself after its implementation. Currently, financing of energy efficiency and sufficient return on investment are one of the most relevant issues of the whole energy efficiency topic.

1.1 Development in European Union

The European Union (EU) has established a new common energy policy aiming at current problems such as: climate change, energy security and establishing the energy union. The key principles of this EU's policy are Green-house gas (GHG) emission reduction, the increase of the share of renewable energy sources (RES) in final energy consumption, and finally the increase of the energy efficiency (EE). Related possibilities as well as suitable measures have been analyzed and implemented in EU-Member States (MS) continually for a decade. The leading role in the fulfilment of the energy efficiency increase has been assigned to the building sector.

The Energy Efficiency Directive (EED) and Energy Performance of Buildings Directive (EPBD) are essential documents developed with the purpose of guiding the EU towards long-term targets regarding reducing energy consumption and GHG emissions. The assumption that lower energy consumption will lead to the decrease of energy poverty, decrease of energy sources dependency and increase of energy security is a crucial argument. Specifically, the most significant energy saving potential lies in the renovation of existing buildings. Due to this fact, deep renovations are considered the most relevant actions in supporting lower energy consumption in the EU countries.

1.2 Motivation

Unexpected dynamics of the sector caused by fluctuating energy prices, many political crises in the recent years, sharply increasing influence of renewable energy sources and the new commitments related to the Paris Conference (UN, 2015), bring many opportunities but also challenges to the EU countries. The latest trends resulted in the so-called Winter package of the European Union. This package includes mainly the Energy union which includes buildings as one of the key instruments. Mr. Maroš Šefčovič, vice president of EU, presented that 70% of EU buildings were found in an unsatisfactory state.

The Czech Republic is not prepared enough for such huge changes in the sector. Dissolved energy agency and energy efficiency and buildings split in more than four ministries which cannot fully support the country in terms of such a huge challenge. The studies included in the thesis are mainly motivated to support a decision-making process of the governmental institutions but also companies and individuals in relation to energy efficiency measures in buildings.

There are still many things to be done, we are facing decreasing demand for subsidies in energy efficiency, low demand for advanced financial instruments and low level of fulfillment of the national target mainly according to article 7 of EED (EP, 2012). However, energy efficiency is one of the quickly developing, and emerging sectors of the national economics (See Annex 2).

Moreover, there is a critical need for newcomers in the building sector. The constantly decreasing number of apprentices will lead to severe lack of construction workers in the future. Increasing attractiveness of the construction industry is a most challenging issue influencing the length of contracts in whole Europe.

1.3 Importance of topic

Energy efficiency and renewable energy sources are topics of a highest priority in the European Union and United Nations. The European Union defined the goals specifically in the field of energy savings, share of renewables and CO_2 emission reduction. The first introduction of these targets was included in the Energy Performance of Buildings Directive in 2002 (EP, 2003). In the follow up documents, 2020 strategy, Energy Performance of Buildings recast in 2010 (EP, 2010), Energy Efficiency directive, 2030 strategy and the so-called Winter Package in 2016 (EP, 2016), the targets were further concretized and strengthened. It brought new topics such as energy union, a new set of targets based on the results of the Paris Conference (UN, 2015), and a pressure to address a better energy poverty topic in the Members States (MS). In parallel, the United Nations defined the topics of the Sustainable Development in the world (UN, 2016). Among those topics, the energy sector plays a major role. Energy efficiency the use of renewables are considered as the chief instruments of energy security in the future. The following priorities were introduced within the energy efficiency topic:

- **No poverty**, Specifically energy poverty topic, homes adequately heated;
- **Good health and well-being**, indoor climate quality, and sick buildings topic;
- **Quality education**, education in how to build and operate new nearly zero energy buildings;
- **Affordable and clean energy**, core of the energy efficiency topic;
- **Sustainable cities and communities**, regional energy management, energy savings in a larger scale;
- **Responsible consumption and production**, saving energy sources and use of RES;
- **Climate action**, specifically lowered use of energy (energy savings) and use of RES.

The author of the thesis contributes to most of the relevant topics within the thesis. He does so mainly via case studies on cost-optimum calculations, energy poverty and evaluation of Green Investment Scheme in the Czech Republic.

Figure 1: Sustainable development goals.
Source: (UN, 2018).

2 Research objectives and Research questions

Currently, there are many gaps in economic evaluation of energy efficiency in buildings. The Czech Republic has decided to invest more than € 3 billion in improving energy efficiency and share of renewables by 2020 (MPO, 2017). However, as in many EU countries, monitoring and targeting leading to the fulfillment of the national target according to Article 7 of EED is insufficient (EP, 2012). A national methodology of energy savings reporting was set up but it does not cover the full range of the indicators needed. The thesis aims to improve the situation with a large scale of methods and approaches suitable for most of energy efficiency programmes, projects and measures. Several results presented in the thesis have already been used to monitor energy savings and RES in the Czech Republic e.g. as documents supporting National Energy Efficiency Action Plan, State Housing Policy or as a National cost optimum calculation. (MPO, 2017)

2.1 Research objectives

The thesis on Economic Evaluation of Energy Efficiency Policies in Buildings aims to introduce various methods used on various levels of decision-making process. The key objective of this thesis is to analyze and evaluate energy efficiency policies in the Czech Republic (mainly from the economic aspect) as well as the recommendations for the policy makers and various market players such as building owners, energy experts, and local authorities.

The work is structured in two main parts: an introductory chapters starting from the Chapter 1 to Chapter 4 and case studies staring from the Chapter 4 to Chapter 8. The introductory chapter covers an introduction of the theme, setting up the objectives, methods and overview of the Energy Efficiency topic. The case studies are dedicated to the Green Investment scheme - ex ante evaluation, Green to Savings - ex post evaluation, Cost optimum calculations and to the programmes to reduce energy poverty. The conclusion chapter summarize the gained knowledge in the field of Energy Efficiency evaluation.

As there is a critical need for evaluation of the Energy Efficiency and Renewables' policies not only in the Czech Republic but also in whole Europe. Specifically, because only via transparent and high quality evaluation, the ambitious targets of energy transformation towards sustainable economics can be achieved. A general objective of the thesis was further divided into the following subobjectives:

- Support of the policy making process for various groups of stakeholders and creation of an information channel from the experts to the policymakers, particularly in technical, economic and legislative issues.
- Create recommendations aiming at strengthening legislative framework especially in the field of the penetration of nearly zero energy buildings and deep renovations of the existing building stock. A special focus is being laid on the recasts of the EPDB and EED directives.
- Develop proposals of the policies addressing energy poverty as one of the potential sources of energy savings. Furthermore, strategies are to be developed to tackle energy poverty via EE mechanisms as vulnerable consumers households are not, by definition, targeted by supporting schemes and thus the energy saving potential is not used at present.

2.2 Research questions

The research objectives are targeting on increasing economic energy savings at various levels of the decision-making process and different market players. Based on the selected objectives, the following research questions have been raised:

- Are the energy efficiency and renewable energy indicators a common and useful part of the energy efficiency policy evaluation?
- What are the cost optimal measures that are reducing energy consumption in the Czech Republic?
- What are the main barriers of the fulfilment of the national EE target in the Czech Republic?
- Is there any replicable approach in the EU countries suitable for reducing energy poverty of vulnerable consumers in the Czech Republic?

The research questions are further examined within the case studies based on the papers and studies published by the author between 2016 and 2018.

3 Methods and data acquisition

As a part of the economic theory, the utility theory is the global method used in the thesis. A building as a property has to fulfil individual requirements of clients creating the environment for most of his/her life. According to the utility theory, consumers always want to maximize their utility given by a particular utility function (Samuelson, 2012). Specifically in building sector, the number of evaluation criteria is very high. It is possible to find dozens of criteria with different preferences for each consumer. Economists use a wide variety of methods (Cost benefit analysis, multi criteria decision making, value for money approach) with the purpose to maximize their utility.

Production functions express a maximum amount of output, which can be produced in the given amount of inputs. In energy efficiency, energy savings are considered to be the output while financial capital, human resources and construction materials are the input. If any part of the chain is missing, the energy efficiency cannot be archived. In 2011 for example, the State environmental Fund interrupted the reception of applications in Green Investment Scheme. This suspension had a huge impact on the newly born market which dropped down and was left by thousands of craftsmen who never came back. Another example can be the year 2014 when the government of the Czech Republic allocated over 3 billion Euro on energy efficiency measures which are to be taken till 2020. However, only less than half of the sources has been allocated so far because of lower demand for the projects and lower absorption capacities.

Currently, there is a critically low number of youth entering the construction market. It is limiting the whole construction industry and influencing duration of the projects. During the boom of Czech economics in winter 2018, the president of the brick producing company promised that the bricks will be fully available in spring. Those are just few examples of the gaps in the construction chain influencing the production in terms of energy efficiency. On the demand side, the client´s. awareness, motivation and sources matter the most. We are currently facing gradually degreasing absorption capacities of the projects. The most efficient projects of market leaders have already been implemented. There are remaining less efficient projects or projects which are more complex from the technical, economic or legal point of view. Many buildings are influenced by the so called log-in effect, limiting future energy savings because only a shallow renovation was implemented. The work focuses on selected parts of the production chain.

3.1 Classification of methods used

The Journal of Economic Literature (JEL) classification is one of the key classifications used in classifying scholarly literature in the field of economics. The system is used to classify articles, dissertations, books, book reviews, and working papers in economic literature, and in many other applications.

In general, the thesis covers the following classes of JEL classification:

Q480 Energy: Government Policy;

Q410 Energy: Demand and Supply, Prices;

The Part titled Energy poverty specifically includes:

D150 Intertemporal Household Choice, Life Cycle Models and Saving;

D180 Consumer Protection;

The Part titled Energy Efficiency policy covers:

H200 Taxation, Subsidies, and Revenue: General.

MSC 2010 Classification

The current 2010 Mathematics Subject Classification (MSC2010) is based on the MSC2000 that has been used since 2000.

91B16 Utility theory, influencing essential thoughts of the thesis;

91B25 Asset pricing models, used in Chapter 7;

91B32 Resource and cost allocation, specifically used in Chapter 5;

91B42 Consumer behavior, demand theory, used in Chapter 8.

3.2 Data acquisition

Within the work on the thesis and supporting case studies, a full range of methods was applied based on an ex-ante and ex-post analyses. The methods went hand in hand with the data collection and data acquisition process. Specifically, the study on Green Investment Scheme uses data collected from the information system of the Programme. However, energy savings, CO_2 emission savings and other indicators were calculated individually for the purpose of the case study. The data used for energy poverty evaluation are based on the statistics of the Czech Statistical Office. The case study on ex-post evaluation of Green Investment Scheme is based on the on-site visit of 206 applications in all 14 regions of the Czech Republic. Data on energy consumption for the cost optimum calculation are produced from the model of Energie software, data on economic parameters of the building are based on the price lists and individual offers of the construction material suppliers. Specific data acquisition process is described in each case study.

In parallel, the question of data availability was solved across the supporting programmes. There was a relatively good ex-ante data for Green to savings programme. However, to provide an ex-post analysis, a fundamental research was conducted through the site visits, interviews and semi-structured questionnaires. In many programmes, e.g. Panel, the data on energy savings and costs were not collected at all. A relatively convenient approach to the data was available via around 700 energy audits conducted in Ekoenergie programme. In the case study on cost optimum, the data was collected mainly from the producers of construction material and the software for the cost estimation (Cross software).

3.3 List of methods used

Due to the character of the work, deterministic methods instead of stochastic approaches were preferably used. According to the Decree on energy performance of buildings (Decree, 2013), the procedure of energy performance calculation is given. The procedure was further followed in the case studies. In general, a detailed literature review was carried out for each of the case studies, including introductory chapters and Chapter 4 on state of the art. The following method and calculation of indicators were used in the thesis.

- Calculation of energy use, used generally;
- Collection of energy consumption in households, used in Chapter 6;
- Abatement cost indicator, environmental-economic indicator used in Chapter 5;
- Greening ratio indicator, environmental-economic indicator used in Chapter 5;
- Payback period indicator, environmental-economic indicator used in Chapter 5;
- Share of subsidy in investment costs, economic indicator used in Chapter 5;
- Indicator of share of administrative costs, economic indicator used in Chapter 5;
- Internal rate of return, economic indicator used in Chapter 5;
- Financial calculation of total specific costs, Life cycle cost method used in Chapter 6;
- Macroeconomic calculation of total specific costs, Life cycle cost method used in Chapter 6;

- Interviews with the building owners and international energy poverty experts, social science method used in Chapter 6;
- Top-down approach, general method specifically used in Chapter 8;
- Bottom-up approach; general method specifically used in Chapter 7;
- Sensitivity analysis; general method specifically used in Chapter 7;
- Histograms; general method specifically used in Chapter 7;
- Conceptual map; general method specifically used in Chapter 8.

Evaluation levels

The thesis covers rather different evaluation levels because of the complexity of the topic and the need to find the so-called devil in the detail. Based on the case studies it is evident that sticking to the governmental level only is not sufficient. The thesis examines the following level:

- Governmental level, mainly in recommendation, and state of the art;
- Level of specific supporting programmes, in the case study on Green Investment Scheme;
- Level of individual measures and projects, in all case studies dealing with energy poverty.

3.4 Introduction of methods

Each case study uses its own set of methods, approaches and indicators fitting best the individual needs of the research. The methods used were proposed by the author and examined via long-term discussions with the policy makers (ministries, funds, European Commission) and reviewing process of the projects and scientific papers. The methods and approaches presented take these evaluations into consideration.

3.4.1 Indicators of effectiveness within Green House Gas emission reduction

The effectiveness of emission reduction is expressed by the Greenhouse gasses (GHG) abatement cost and greening ratio indicators. **GHG abatement cost indicator (**AC_{GHG}**)** expresses financial costs in relation to units of reduced CO_2 emissions. It can be identified as a ratio of total costs (TC) in Euros, as well as the subsidy for measures leading to the reduction of GHG emissions compared to total GHG emissions reduced, (RE_{GHG}) in tons of $CO_{2\text{-eq}}$. (Honzík, et al., 2013)

The results of the indicators are expressed in units of currency showing the amount of reduced emissions - $€ \cdot tCO_{2red}^{-1}$. In cases of replacing original technologies with a low-emission (alternative) technology, the indicator may be expressed as the ratio of the difference of costs between the alternative (C_{AS}) and the original source (C_{RS}) and the difference of emissions from the original (E_{RS}) and alternative source (E_{AS}) (see Equation 1).

***Equation 1:* GHG abatement cost indicator**

$$AC_{GHG} = \frac{TC}{RE_{GHG}} = \frac{C_{AS} - C_{RS}}{E_{RS} - E_{AS}}$$

In this thesis, a condition without change was considered to be the original state, i.e. an uninsulated building or heated by using fossil fuels (original heat source). Therefore, only the costs of the measures applied were included in the calculation (insulation or a new heat source).

In cases of reduced energy consumption of buildings (insulation) and supported construction of low-energy-requirement housing, the reduction of CO_2 emissions was calculated from the difference of emissions arising from the energy requirement for space and hot water heating, before and after applying the measures, which were converted by using adjusted emission coefficients (conversion to consumption). The costs of material, installation work and delivery (including VAT) were included in the total costs for the implementation of the measure.

Greening ratio indicator (GI) is a non-unit quantity that expresses the effectiveness of funds used from sales of AAU for the purpose of reducing CO_2 emissions. It may be expressed as a ratio of 1 toward the ratio of sold and reduced CO_2emissions. The value of GI may be obtained through the ratio of the investment support (IS) in Euros and a multiplication of the price per sold AAU unit (P_{AAU}) and the amount of reduced emissions expressed in tons of $CO_{2\text{-}eq}$ (RE_{GHG}) as shown in Equation 2 (Honzík, et al., 2013).

The calculations used pricing of 10 € per AAU. This value arises from the method of verifying savings of emissions of the Programme (Honzík, et al., 2013). This pricing was used as there was the need to allow a comparison of applied measures within various tranches which, in the realistic sense, showed a differing price for the AAU. For example, a newly installed biomass boiler, implemented at various times during-the Programme, shows the same greening in the case of identical parameters.

Equation 2: **Greening ratio indicator**

$$GI = 1 : \frac{IS}{P_{AAU} . RE_{GHG}}$$

In case of a greening value achieving 1: >1, less GHG emissions were reduced than those sold. In case of the results 1:<1 the reduction of CO_2 was greater than sold in terms of AAU and thus an effective use of the financial fund was achieved in reducing GHG.

3.4.2 Economic indicators

For the return on investment indicator (Payback Period), a ratio of the subsidy in the investment costs, a ratio of administrative costs on the total cost and the IRR indicator were used to evaluate the economic effectiveness of the measures applied.

The payback period indicator (PP) expresses the number of years that elapse before the investment costs for the measures implemented equal savings in the costs of space and water heating. The payback period may be found in the ratio of total investment costs for the measure (Investment Costs – IC) in Euros and the annual savings for heating (see Equation 3). The annual savings in the cost of space and water heating were obtained by multiplying the annual energy savings (ES_a) in kWh by the price of energy (P_E) for space and water heating according to the individual energy medium, expressed in Euro per kWh.

PP was calculated both from the side of the applicant (from the perspective of the support) as well as from the macroeconomic point (without considering the support). (Honzík, et al., 2013)

Equation 3: **Payback period indicator**

$$PP = \frac{IC}{ES_a \cdot P_E}$$

Share of subsidy in investment costs (S_{IC}), expressed in percentages, is an important indicator of the effectiveness of funds spent, from the perspective of the state or the purchaser of AAU. IS represents the investment subsidy in Euro and IC are investment costs in Euro (see Equation 4). The investment subsidy was calculated for the individual areas of measures for both new buildings and renovations.

Equation 4: **Share of subsidy in investment costs**

$$S_{IC} = \frac{IS}{IC} \cdot 100$$

Another important economic indicator of the Programme is the ratio of administrative costs per measure. Administrative costs express effectiveness of project administration from the perspective of the administering institution (Valentová & Honzík, 2011). The goal of the whole programme of support is to minimize such costs, because they bear no direct positive impact on the GHG emission savings or energy savings.

The indicator of the share of administrative costs (S_{TC}), expressed in percentages, was selected as it can be compared with other subsidy programmes. The calculation is established as a share of administrative costs (AC) in Euros and total costs (TC) in Euros (see Equation 5).

Equation 5: **The indicator of the share of administrative costs**

$$S_{TC} = \frac{AC}{TC} \cdot 100$$

Another indicator supporting the comparison on both national and international level is the calculation of **Internal rate of return** (IRR), in percentage. The purpose of the calculation is to achieve a maximum comparability with an assumption of the fifteen-year lifespan of the measure (mainly according to the lifespan of the technologies). The basic entry data of the calculation was cash flow (CF_t) in Euros in periods *t* and investment costs of the measure (IC) in Euros (see Equation 6). The IRR calculation was done both with and without consideration of the share of subsidy. With consistent prices, the calculation was performed without including the tax.

Equation 6: **The indicator of internal rate of return**

$$\sum_{t=0}^{15} CF_t . (1 + IRR)^{-t} - IC = 0$$

The indicator of the net present value (NPV) was not used, due to low comparative quality because NPV is dependent upon the size of the measure implemented. Therefore, the indicator above is not suitable for comparing diverse measures that occurred within the Programme.

Financial calculation of total specific costs

The main method consists of a comparison of various procedures used to determine the costs of energy efficiency measures. The basic approach lies in determining the costs of the measures by means of a costs calculation; however, the experience has shown that catalogue prices and supply prices vastly differ. Therefore, particular key items were compared to bid prices or prices offered by building materials producers. In order to gain the information needed about the sale prices of building materials, building material sellers were consulted.

The prices of building materials used during a renovation as a measure for improving a building's energy performance were obtained by request and by analysing the market for each locality in the country.

Financial calculation of cost optimum involves initial investment costs, annual replacement costs and running costs (i.e. maintenance and operating costs, energy costs or, if appropriate, profit gained from on-site generated energy). When applicable, disposal costs can be included as well. Furthermore, residual value of elements whose lifetime expires at the end of the calculation period is considered. Financial calculation takes into account costs including all taxes, fees and subsidies where applicable, etc.

Financial calculation was carried out for two different discount rates. The assessment period has been set for the period of 30 years for residential and public buildings and 20 years for commercial (non-residential) buildings.

The calculation takes into account only immediate costs and benefits of the investment decision, (ČSN 73 0540-2, 2011). A general formulation of the economic calculation under the standard (ČSN EN 15459, 2010) determines quantifiers to calculate total specific costs. Unfortunately, the use of this standard is not commonly used. As to financial calculation, the following applies.

Calculation of total specific costs according to the standard (ČSN EN 15459, 2010) – financial calculation (Guidelines accompanying Commission Delegated (Regulation 244/2012, 2012) (EU) of January 16, 2012)

***Equation** 7:* **Calculation of global costs**

according to the standard ***(ČSN EN 15459, 2010)*** – financial calculation (Guidelines accompanying Commission Delegated ***(Regulation 244/2012, 2012)*** (EU) of 16 January 2012)

$$C_g(\tau) = C_I + \sum_j \left[\sum_{i=1}^{\tau} \left(C_{a,i}(j).R_d(i) \right) - V_{f,\tau}(j) \right]$$

$C_g(\tau)$ means global cost (referred to starting years) over the calculation period (30 years);

C_I initial investment costs for a measure or a set of measures;

$C_{a,i}(j)$ annual cost during the year i for a measure or a set of measures j;

Annual costs are defined as replacement costs for an element or system during the year I;

$C_{a,i}(j) = C_r + C_p(i)$

C_r energy costs, annual maintenance and operating costs and other costs;

$C_p(i)$ periodic costs during the year i (i.e. element recovery at the end of its lifetime);

$R_d(i)$ discount factor for the year i based on the discount rate r;

$V_{f,\tau}(j)$ residual value of a measure or a set of measures j at the end of the calculation period (discounted to the starting year).

Macroeconomic calculation of total specific costs

The goal of this calculation approach is to involve aspects considering the society as a whole in the mathematic optimisation model. We call it internalization of externalities. Macroeconomic calculation should not involve any taxes, fees or subsidies in its cost headings. On the other hand, it should include the costs of greenhouse gas emissions calculated using cumulated carbon costs for the calculated period (through prices of emission allowances) and thus consider the aforementioned social aspects.

Like in LCC calculation methodology, macroeconomic calculation also considers main externalities which are otherwise not included in financial calculation (e.g. CO_2 emissions involved in the investment cost). Consequently, the Member States are asked to carry out sensitivity analyses for relevant input parameters.

The following applies to macroeconomic calculation:

Equation 2 – Calculation of global costs

according to the standard (ČSN EN 15459, 2010) – macroeconomic calculation (Guidelines accompanying Commission Delegated (Regulation 244/2012, 2012) (EU) of 16 January 2012)

$$\boldsymbol{C_g(\tau) = C_I + \sum_j \left[\sum_{i=1}^{\tau} \left(C_{a,i}(j).R_d(i) + C_{c,i}(j)\right) - V_{f,\tau}(j)\right]}$$

$C_{c,i}(j)$ Carbon costs for a measure or a set of measures j during the year i

$C_g(\tau)$ means global cost (referred to starting years) over the calculation period (30 years);

C_I initial investment costs for a measure or a set of measures;

$C_{a,i}(j)$ annual cost during the year i for a measure or a set of measures j;

Annual costs are defined as replacement costs for an element or system during the year I;

$C_{a,i}(j) = C_r + C_p(i)$

C_r energy costs, annual maintenance and operating costs and other costs;

$C_p(i)$ periodic costs in the year i (i.e. element recovery at the end of its lifetime);

$R_d(i)$ discount factor for the year i based on the discount rate r;

$C_{c,i}(j)$ Carbon costs for a measure or a set of measures j during the year i

$V_{f,\tau}(j)$ residual value of a measure or a set of measures j at the end of the calculation period (discounted to the starting year).

Example of CO_2 savings calculation

The CO_2 savings calculation is based on results of the energy performance certificate method applied and additional data collected. Each measure and each combination of measures has its own equation. An example of calculation for insulation is introduced bellow.

Equation 8: **Calculation of CO_2 savings for insulation measures**

$$\mathrm{CO}_{2Savings} = (c_{bf} * s_{bf} - c_{af} * s_{af}) * 3.6 * K_e/1000$$

Where:

c_{bf} is specific annual heat demand in the building before implementation of the measures [kWh/(m^2.a)];

S_{bf} is total floor area of the building before implementation of the measures [m²];

c_{af} is specific annual heat demand in the building after implementation of the measures [kWh/(m².a)];

S_{af} is total floor area of the building after implementation of the measures [m²];

K_e is corrected CO2 emission factor according to the type of initial heat source [kg/GJ$_{corr}$].

Bottom up modelling

A Bottom up modelling is a very useful instrument for predicting energy consumption of each energy carrier and future costs for energy for various target groups. Specifically, the following model was used to develop energy consumption scenarios of the EU countries within the Intelligent Energy Europe (IEE) project (ENTRANZE, 2012). The model is based on a deep knowledge of the building stock statistics including climate data, demography and economic factors. In parallel, advanced modelling approaches are being used. The model results have bee complete in 2014 and presented with ENTRANZE IEE project.

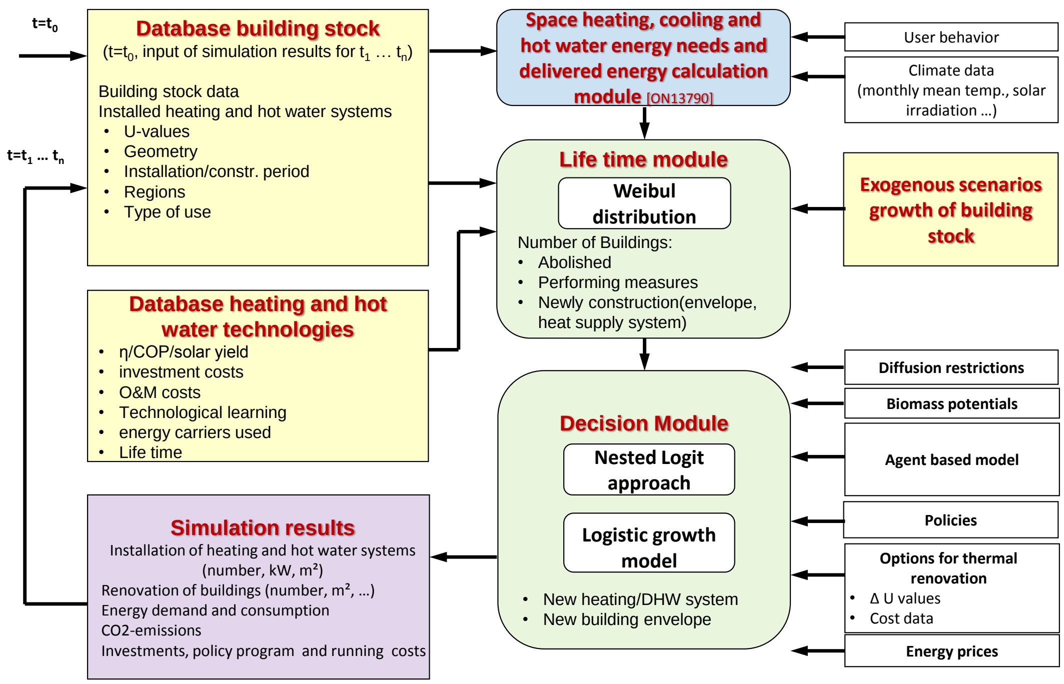


Figure 2: ***Overview structure of Simulation-Tool Invert/EE-Lab.***
Source: (ENTRANZE, 2012).

4 State of the art in Energy Efficiency and Renewable Energy policy implementation

Pursuant to Directive No. 2012/27/EU of the European Parliament on energy efficiency (EED), a requirement has been laid down to generate savings in the final consumption of 1.5% per year. The Czech Republic has chosen an alternative scheme that aims to generate the required energy savings through programmes that promote energy efficiency. In contrast to other European countries, the portfolio of policy measures is rather narrow. What other ways are there to widen the scope of policy measures to promote energy efficiency and fulfil the objectives of the Directive by 2020. (MPO, 2017)

In comparison with other European countries, the Czech Republic has chosen an alternative scheme and a portfolio of policy measures focused primarily on measures concerning subsidies in the building sector. The current delay in energy savings generated by new operational programmes, a lower achieved allocation of programmes and modifications in the projects´ structure within particular programmes are responsible for the assumption that the savings achieved in their final energy consumption are lower than expected.

The savings might be increased by jump-starting programmes that promote subsidies defined in the National Action Plan on Energy Efficiency. (MPO, 2017) Another way would be to widen the portfolio of policy measures and possibly greater involvement of energy suppliers. A range of issues needs to be considered while choosing possible solutions defined by Article 7 of the Directive: Choosing a scheme for the period starting in 2017 – involvement of the state and energy suppliers choosing policy measures, e.g. subsidies, training, information campaigns, etc. The importance of support for training towards nearly zero-energy buildings or towards "deep renovation" involves setting of new national targets relating to energy savings pursuant to Article 7 EED, methodological questions, assessment of the issue regarding double counting of savings as well as the additionality and materiality of such measures. (Karásek & Pavlica, 2016)

4.1 Approach to Energy Efficiency legislation in European Union countries

The approach to legislation on EE exists on two different levels: EU level and the level of particular EU countries. The umbrella documents are approved at EU level and implemented in the national legislation of EU Member States, typically through energy acts, decrees and regulations. Directive 2010/31/EU of the European Parliament, known as EPBD 2, governs the energy performance of buildings in the EU

Member States. EPBD 2 follows on from EPBD 1 which launched the process of enhancing and monitoring the energy performance of buildings in all EU countries (EP, 2003) (EP, 2010).

European leaders committed themselves to reduce primary energy consumption by 20 % compared to projections for 2020. Energy efficiency is the most cost-effective way of reducing energy consumption while maintaining an equivalent level of economic activity. Improving energy efficiency also addresses the key energy challenges of climate change, energy security and competitiveness (EP, 2010).

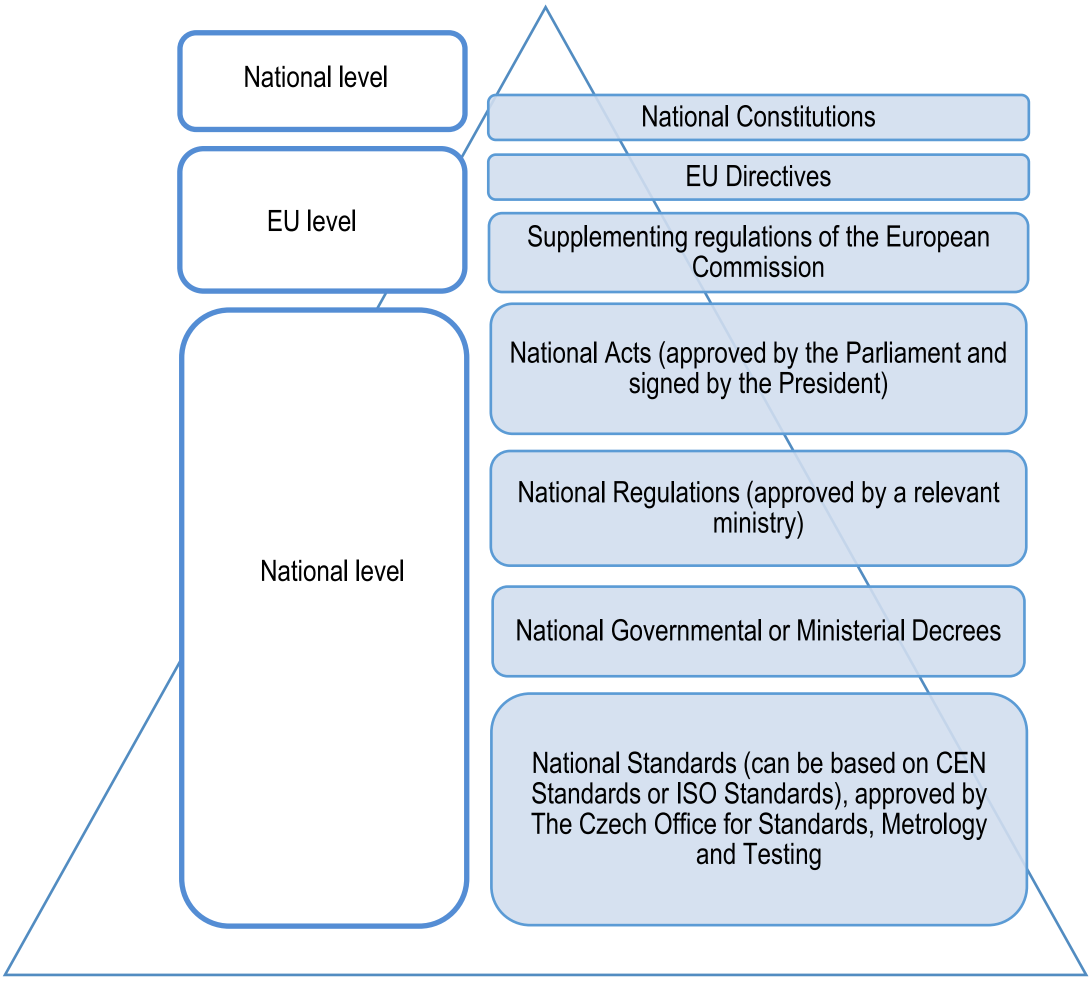


Figure 3: Structure of the national and EU law.
Source: (Karásek, 2013).

Energy saving is the EU's most immediate and cost-effective way of addressing the key energy challenges of sustainability, security of supply and competitiveness as set out in the strategic objectives of the 'Energy Policy for Europe'. EU leaders have stressed the need to increase energy efficiency as part of the '20-20-20' goals for 2020: saving 20 % of the EU's primary energy consumption, a binding target of 20 % reduction of greenhouse gas emissions and 20 % increase in the use of renewable energies by 2020.

Energy use in residential and commercial buildings is responsible for about 40 % of EU's total final energy consumption and 36 % of the EU's total CO_2 emissions. The cost-effective energy saving potential by 2020 is significant: 30 % less energy use within the sector is feasible. This equals the reduction of 11 % use of the EU's final energy. However, energy use in this sector continues to increase (EP, 2010).

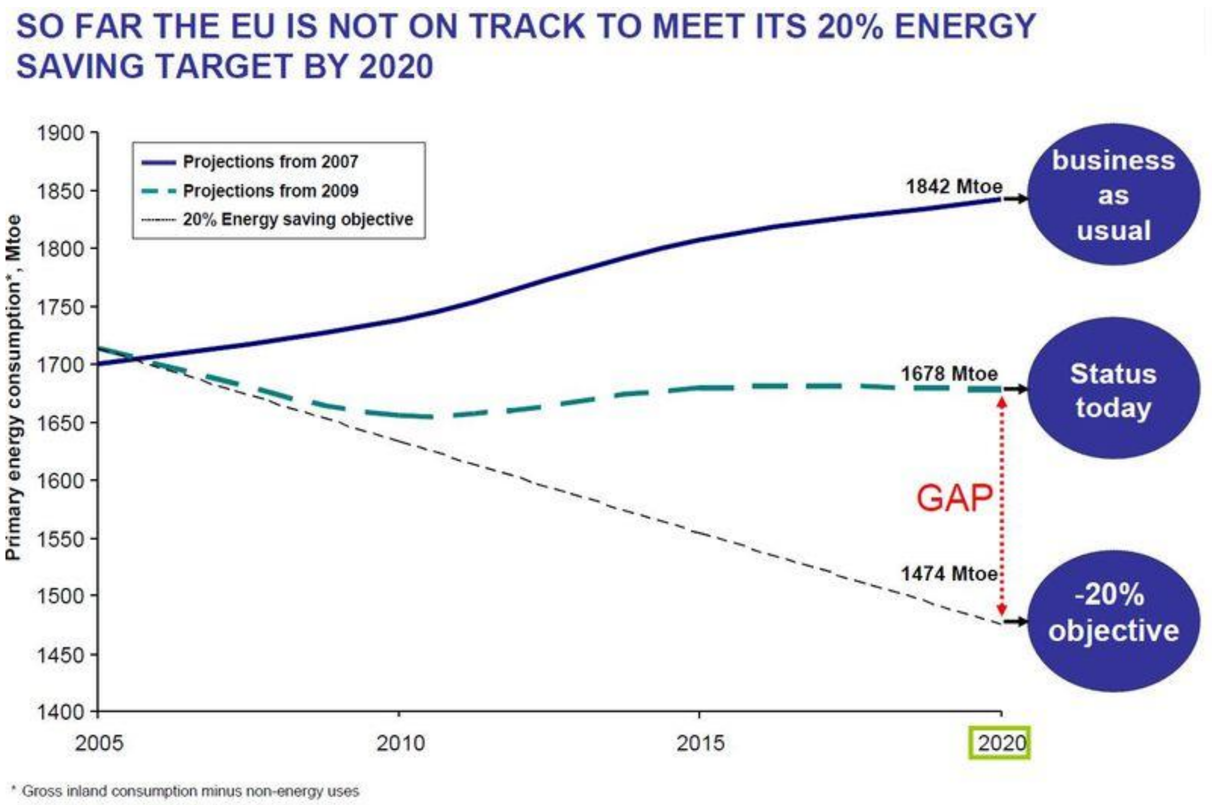


Figure 4: Projections of the primary energy consumption.
Source: (EP, 2012).

4.2 Basic legal documents related to Energy Efficiency

Directive 2002/91/EC EPBD 1

This Directive sets out the following main requirements to be implemented by the Member States:

- A methodology for calculating the integrated energy performance of buildings;
- The application of minimum requirements on the energy performance of new buildings;
- The application of minimum requirements on the energy performance of large existing buildings that are subject to major renovations;
- Energy performance certification of buildings;

- Regular inspection of boilers and air-conditioning systems in buildings and in addition an assessment of heating installations in case the boilers are more than 15 years old;
- Requirements for experts and inspectors for the certification of buildings, drafting of the accompanying recommendations and the inspection of boilers and air-conditioning systems. (EP, 2003)

Directive 2010/31/EU (EPBD 2)

EPBD 2 defines basic approaches and rules to achieve low energy consumption in buildings (i.e. higher energy performance) by calculating energy performance in buildings, taking into account the energy delivered for heating, cooling, hot water preparation, ventilation, lighting and auxiliary energy.

According to this Directive, all new residential buildings will have 'nearly zero energy consumption' by 31 December 2020 (and all new public buildings by 31 December 2018).

EPBD 2 clarifies, strengthens and extends the scope of EPBD 1's provisions by:

- Introducing clarification of the wording of certain provisions;
- Extending the scope of the provision requiring the Member States to set up minimum energy performance requirements when a major renovation is to be carried out;
- Reinforcing the provisions on energy performance certificates (and inspections of heating and air-conditioning systems), energy performance requirements, information and independent experts;
- Providing the Member States with a benchmarking calculation instrument which allows the nationally (or regionally, if relevant) determined minimum energy performance requirements´ ambition to be compared to cost-optimal levels;
- Stimulating the Member States to develop frameworks for higher market uptake of nearly zero energy (and carbon) buildings (EP, 2010).

Directive 2009/28/EC on the promotion of the use of energy from renewable sources

This Directive establishes a common framework for the promotion of energy from renewable sources. It sets mandatory national targets for the overall share of energy from renewable sources in the gross final consumption of energy, and for the share of energy from RES in transport. It also establishes sustainability criteria for biofuels and bioliquids.

4.3 Ownership of buildings

The ownership of buildings is a crucial factor in increasing EE. Defining the roles of building owners, tenants and the state is a highly important issue in effective building operation and decision-making influencing EE. There are significant differences in the structure of ownership and decision-making among EU countries. Well known are the cases e.g. in Bulgaria where the owner insulate his or her part of façade. Various approaches can be based on family housing, apartment buildings, private non-residential buildings and public buildings.

Family houses are typically owned by an individual. The ownership and decision-making process is relatively simple. The responsibility for taking measures lies with the owner; the financing of EE measures therefore depends on the owner's own sources and the country's financial environment (supporting schemes).

Owner-occupied single-family homes is the only category that is fairly similar in all countries. In several countries, owner-occupied single-family homes are the most dominant and common type of home in urban (or suburban) areas, whereas in others they mainly occur in rural areas and in wealthy suburban villa areas. The apparent homogeneity between countries thus masks heterogeneity therein, to some extent.

In contrast, the share of rented single-family homes varies greatly (and unfortunately is not known for all target countries). At its highest share it amounts to 9 % of the total building area, while the smallest share is 0 %. In most cases they are owned by private individuals. In terms of ownership, apartment buildings are the most heterogeneous type of buildings.

The differences in the ownership structure are much greater still in multi-family buildings. Here, some countries have a predominant share of owner-occupancy. Furthermore, the structure of decision-making within owner-occupied apartment buildings varies greatly. There are approximately four main models of apartment building ownership and use in Europe. The type of ownership influences the decision-making system and the owners' power and possibility to make decisions (ENTRANZE, 2012)

- Non-profit housing associations are considered to be groups with a very positive attitude towards implementing energy improvements. The residents exercise influence through their participation in decision-making processes related to the property. Their resources are systematically set aside for continuous maintenance and improvements, and the investments benefit for the residents are attained through subsequent energy savings.

- Private cooperative flats: Housing cooperatives are considered to have a relatively positive attitude towards implementing energy improvements. Cooperative housing is often in a better energy condition than owner-occupied flats or private rented flats. Residents benefit from investments through subsequent energy savings. It varies from one housing cooperative to another whether resources are continuously set aside for maintenance and improvements. However, it is possible to raise a loan collectively in housing cooperatives.
- Owner-occupied flats: Energy saving initiatives will benefit the individual owners of flats. However, owners are believed to have a stronger focus on individual improvements to their own flat than on common improvements to the property. It is an important factor that loans are raised for each flat individually, and that the return will not be released until a subsequent sale.
- Private rental flats: Extensive legislation exists to regulate housing conditions in private rented housing. The owner decides on and must be able to see the benefit of investing in improvements. Investments in energy improvements can lead to an increased rent, in accordance with the rules as to the added value of the rented property. The residents enjoy the subsequent energy savings. (ENTRANZE, 2012)

Private non-residential buildings are mainly owned by one private company which facilitates its assets. Approaches to increasing EE are related to the company's priorities and strategy and EE measures compete with other investment possibilities. Only the most economically efficient measures are implemented. However, compliance with the norms and standards must be ensured. The retrofitting of historical buildings, for example, can involve complex problems.

Public buildings owned by the state, state institutions or municipalities form a very heterogeneous group of buildings, requiring different approaches. The public building sector includes buildings with very different purposes, from offices to theatres and from historical buildings to new, modern buildings. Long-term strategies and activities should be established to find a suitable approach to the specific conditions of these heterogeneous types of buildings.

4.4 Energy efficiency and RES requirements

Energy efficiency requirements are established at national level. Each country has its own EE requirements created according to its own methodology. After the EPBD's implementation, the methodology will be common to all Member States. The requirements are related to the climate and building stock conditions in the country.

An important group of parameters is highlighted by the energy performance of a building. This refers to the calculated or measured amount of energy needed to meet the energy demand associated with the typical use of the building which includes, inter alia, energy used for heating, cooling, ventilation, hot water and lighting. (EP, 2010)

The next EE parameter defined at EU level by EPBD 2 is natural and mechanical ventilation which may include air-tightness. The tightness parameters are typically included for new low-energy standard buildings, and defined at national level. National laws may also stipulate the obligation to perform blower door tests. However, nationally, the tests are obligatory just for the supporting programmes.

The last of the most important EE parameters included in EU law is primary energy. Primary energy means energy from renewable and non-renewable sources which has not undergone any conversion or transformation process. From 1st January 2013 onwards, the calculation of primary energy (both total primary energy and non-renewable primary energy) has been mandatory and must be included in energy performance certificates. For a building, total primary energy is the energy used to produce the energy delivered to the building. It is calculated from the delivered and exported amounts of energy carriers, using conversion factors and including generation losses for each energy carrier.

4.5 Energy audits

An energy audit is a very detailed description of a building, its systems and installed technology, based on the actual consumption invoiced (operational rating). There are over 50 standards related to the Energy efficiency and energy audits.

EU standards

The system of European standards is based on the European Committee for Standardization (CEN). CEN is a major provider of European standards and technical specifications. This organisation has 31 members (countries) which cooperate to develop common rules that are applicable in each Member State. As a consequence, each MS can implement CEN-based standards, abbreviated as ‘EN’, in its national standard system. As the systems in each Member State vary, it is possible to incorporate national values, notices or partial changes, for example according to weather conditions or other specific features. CEN has a ‘compatibility agreement’ with the International Organization for Standardization (ISO) which works on a similar basis but also extends outside Europe.

European Standards (EN) usually includes practical methodologies and approaches for selected part of EE. After adaptation at European level, they are adopted and implemented in the Member States.

The most important technical standards (norms) regulating energy audits and energy performance certificates

The following standards are presented in a version used in the case studies in Chapters 5 - 8:

- EN 15217 Energy performance of buildings – Methods for expressing energy performance and for the energy certification of buildings, currently replaced with EN ISO 52003-1 (730324) Energy performance of buildings -- Indicators, requirements, ratings and certificates -- Part 1: General aspects and application to the overall energy performance
- EN 15459 Energy performance of buildings – Economic evaluation procedure for energy systems in buildings;
- EN 15603 Energy performance of buildings – Overall energy use and definition of energy ratings; currently replaced with EN ISO 52000-1:2017 Energy performance of buildings -- Overarching EPB assessment -- Part 1: General framework and procedures and ISO/TR 52000-2:2017 (2017) Energy performance of buildings -- Overarching EPB assessment -- Part 2: Explanation and justification of ISO 52000-1;
- EN 15316 Heating systems in buildings;
- EN ISO 6946 Building components and building elements – Thermal resistance and thermal transmittance – Calculation method;
- EN ISO 13790 Energy performance of buildings – Calculation of energy use for space heating and cooling, currently replaced with ISO 52016-1:2017 Energy performance of buildings -- Energy needs for heating and cooling, internal temperatures and sensible and latent heat loads -- Part 1: Calculation procedures;
- EN ISO 13789 Thermal performance of buildings – Transmission and ventilation heat transfer coefficients – Calculation method;
- EN ISO 13370 Thermal performance of buildings – Heat transfer via the ground – Calculation methods.

4.6 Energy performance certificates

Energy Performance Certificate is a certificate recognised by a Member State or by a legal person designated by a state and indicates the energy performance of a building or building unit, calculated according to a methodology adopted in accordance with Article 3 of Directive 2010/31/EU. (EP, 2010)

The importance of energy performance certificates in Europe is rising. Energy performance certificates are one of the most important motivational factors for implementing EE measures in buildings.

Energy performance certification is a methodology for establishing the energetic qualities of various building types according to a common scale. The energy performance certificate establishes a valuable metric for comparing buildings of similar types within and across countries and for making otherwise complex thermodynamic calculations accessible to experts and non-experts alike. For instance, buyers and tenants may compare different buildings or houses and thus are given the opportunity to save on energy bills by purchasing or renting a more efficient building. Conversely, sellers and property owners may purchase a cheaper but less efficient building, with the intention of adding on value to the property, thereby using a building's efficiency rating as a prime selling point for energy conscious prospective buyers/tenants. Energy performance certification in the European Union is part of a policy directive geared towards improving the EE of the building stock by introducing a methodology for quantifying energy performance which is flanked by a set of minimum energy performance requirements for certain types of buildings.

Crucially, an energy performance certificate, as set out in the European directives, is designed to be a dynamic measure of a building's energy performance. This stands in contrast to other approaches that assess only the energetic characteristics of individual building components (windows, walls, ceilings, etc.). The EU energy performance certificate methodology explicitly focuses on the energy demand associated with the typical *use* of a building – i.e. energy expended on heating, cooling, ventilation, hot water and lighting.

Table 1: Overview of energy performance certification in selected EU countries.

Country	Responsibility	Assessment method
Austria	Partly national and regional	Calculated rating only
Belgium	Regional	Combination – Measured rating for public buildings, calculated rating for other buildings
Czech Republic	National	Calculated rating only
Denmark	National	Calculated rating only
France	National	Combination of calculated and measured rating
Germany	National	Combination of calculated and measured rating
Hungary	National	Combination of calculated and measured rating
Ireland	National	Calculated rating only
Netherlands	National	Calculated rating only
Poland	National	Calculated rating only
Portugal	National	Calculated rating only
Spain	Partly national and regional	Calculated rating only

Source: (Karásek, 2013).

Main features and issues of energy performance certification

- Calculation methodology: asset or operational rating[1] - almost all EU countries use only one methodology; approximately 70 % of Member States use asset rating;
- The main evaluation parameter: useful energy, delivered energy (end energy) or primary energy;
- One or more types of energy performance certificate for new/renovated buildings, for selling/renting and for display purpose[2] – almost all Member States use only one type of energy performance certificate; One or more types of energy performance certificate for building types– almost all Member States use only one type of energy performance certificate;
- Issuing the energy performance certificates for separate flats only, for whole buildings, or for both – approximately 50 % of Member States use the 'whole building' evaluation methodology only, approximately 30 % of Member States use 'separate flat' evaluation, and approximately 20 % of Member States use both methodologies;
- Main evaluation scale – stepped scale with letters, or a continuous scale;
- Limitation of the number of recommendations proposed in the certificate - approximately 30 % of Member States define a minimal number of recommendations (usually 3-5 measures);
- Who is responsible for acquiring the energy performance certificate in case of building/renovating, selling/renting, or for display purposes;
- Different types of control mechanisms;
- Training of experts and examination procedures and licensing, etc.

EU Member States shall ensure that the energy performance certification of buildings and the inspection of heating systems and air-conditioning systems are carried out in an independent manner by qualified and/or accredited experts, whether operating in a self-employed capacity or employed by public bodies or private enterprises (EPBD 2, 2010).

EU states shall provide information on training and accreditations. The Member States shall ensure that either regularly updated lists of qualified and/or accredited experts or regularly updated lists of accredited companies which offer services of such experts are made available to the public (EPBD 2, 2010). For

[1] Asset rating is provided according to standardized operation of the building. Operational rating is provided according to measured energy consumption in the building.

[2] It means that the Energy performance certificate is available on a visible place in the building so evaluation of the building can be accessible to the public.

example, energy experts in the Czech Republic are divided into four independent groups: energy audits, inspection of heating systems, inspection of air-conditioning systems and energy performance certificates. The list of energy experts is compiled by the Ministry of Industry.

4.7 Energy performance contracting

An energy service company (ESCO) providing energy performance (EPC) contracting services *"is a natural or legal person that delivers energy services and/or other energy efficiency improvement measures in a user's facility or premises and accepts some degree of financial risk in doing so. The payment for the services delivered is based (either wholly or in part) on the achievement of energy efficiency improvements and on meeting he other agreed performance criteria."*

Energy performance contracting together with energy fund, community funding and crowdfunding are an innovative financial instruments. All have been favoured as they are independent of government budgets. If used properly, they can provide long-term financial support that often cannot be guaranteed due to the changing budget priorities of national governments. Energy Performance Contracting has been deployed in Europe since the 1980s, while Energy Efficiency Obligations started in the early 1990s in a few Member States.

Energy Performance Contracting is a method that is on the increase, and which will continue to be so in the upcoming years. It is a useful tool in helping owners to increase the energy efficiency of their buildings without using their own financial resources.

In the broader sense, services provided by ESCOs can be seen as an effective tool for lowering energy demands. The EU also sees this issue in a similar light and has prepared the background material for integrating these services into the legislative systems of the individual EU Member States.

Energy performance contracting is the method used by ESCOs with the aim of reducing energy consumption and the subsequent costs in customers' buildings. With energy performance contracting, the main source of payment for the energy saving measures is the actual saving on energy consumption (or running energy systems) achieved by measures defined in the contract between the supplier (ESCO) and the customer.

The length and wording of the contracts depend on specific conditions, such as technical factors (the level of saving), economic factors (the stability of the external environment and the subject concerned, the amount of certain financial and economic indicators – interest rates, price increases, etc.), and legal factors (current contracts with energy suppliers, the customer's legal status). Additional financial sources are provided by a third party subject (financial institutions).

Examples of good practice can be found in many EU countries (Germany, Austria, France, the Czech Republic, etc.) and in the USA, as this method is often very well developed and commonly used in the public sector. (EUESCO, 2018)

4.8 Implementation of Nearly Zero Energy Buildings

nZEB requirements are gradually entering into force in the Czech Republic. They are based on Directive 2010/31/EU of the European Parliament and of the Council on the energy performance of buildings. At the Czech national level, some of the requirements of the European directive have been transposed by means of an amendment to Act No. 406/2000 Coll., on Energy Management, as amended. The technical part of the requirements is specified by Decree No. 78/2013 Coll., on the Energy Performance of Buildings, as amended by Decree No. 230/2015 Coll.

European Directive 2010/31/EU obliges EU Member States to establish a national nZEB definition according to their legislative conditions, customary construction procedures, technologies used, climatic conditions, etc. However, not all Member States can offer an approved national nZEB definition. For example, in Greece, Portugal and Poland the definition is still in the preparatory phase. (ZEBRA; 2017)

A pan-European comparison indicates that there are some countries left which still have not adopted the nZEB definition as no agreement at the national level has been reached. On the other hand, approaches to the definition differ, e.g. the approach to the classification of energy performance of buildings, the so-called reference building or specific values for various building types. Some countries have a given renewables share and indicator for CO_2 emissions.

Over the long-term, directives on energy performance of buildings and energy efficiency definitely have a positive impact on the household sector, as the requirements defined by the directives lead to significant energy and financial savings. Generally, the main requirement for introducing measures is their economic, environmental and technical feasibility and appropriateness. Therefore, it is ensured that the requirements for introducing measures are meaningful, feasible and cost-effective.

A study called Development and Impacts of nZEB Buildings Introduction provides data on energy savings achieved by energy savings in buildings. Thanks to nZEB, total energy savings should be from 74 up to 114 PJ per year, depending on the specific development scenario. The new nZEB buildings savings alone represent 33 up to 56 PJ per year. These savings pertain to the residential sector, while savings in the non-residential sector represent another potential component.

In terms of impact on the property market, no substantial change or problems retarding development should be expected. The extra costs for nZEB are marginal in terms of the overall costs and their higher purchase price will be offset by energy savings and reduced operating costs.

Moneywise, the increase of energy efficiency (which usually means higher RES share and reduced CO_2 emissions) is fairly demanding for households, but in the end brings lower operating costs. An optimal combination of the impact on energy efficiency and the amount of household expenses is given by a cost optimal level described in the study for several types of dwellings in the tertiary sector.

The impact of energy savings on Czech energy is crucial. They will influence so-called large energy, primary energy sources and their consumption as well as transformation processes (particularly as far as their volume and number of individual sources are concerned). Energy savings will also influence investments in new sources of heat and electricity.

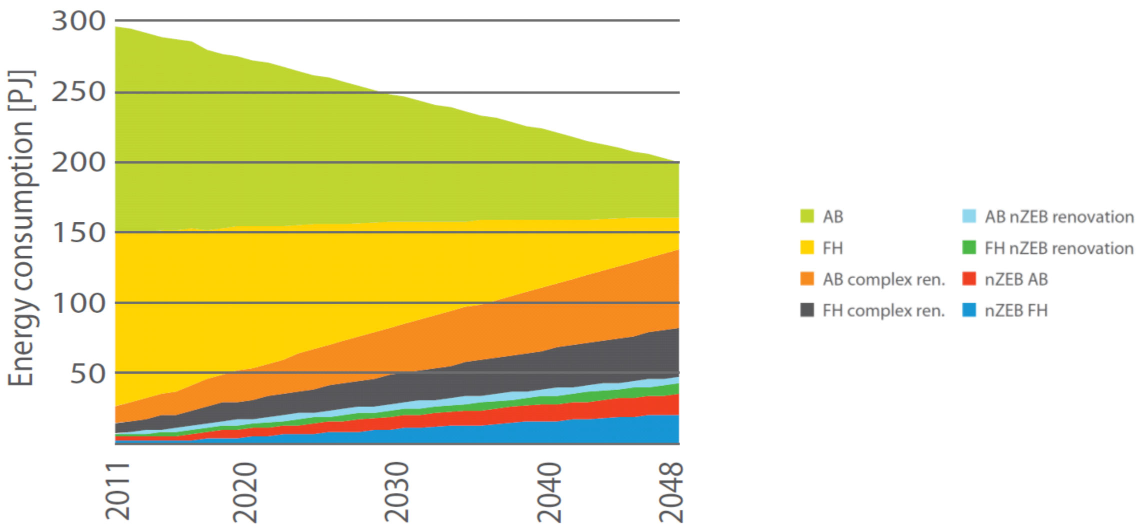


Figure 5: Expected development of energy consumption in residential buildings by 2050.
Source: (Karásek, 2016).

5 Case Study on Evaluation of Green Investment Scheme

The case study was performed within the evaluation process (2009-2016) of the Green Investment Scheme in the Czech Republic and later published in Energy Policy journal as (Karásek & Pavlica, 2016).

5.1 Description of the case study

The reduction of greenhouse gas emissions (GHG) is a long-term problem and the possibilities for lowering these emissions and proposing suitable measures are continually analyzed in nearly all developed countries. The basic document of the United Nations Framework Convention on Climate Change (UNFCCC, 2008) is the Kyoto Protocol that was created with the goal of decreasing negative impacts in relation to global climate change.

Within the Kyoto Protocol, 37 developed countries undertook to lower their GHG emissions by the end of 2012 by 5.2%, compared to their initial value in 1990 (UN, 1998). The United Nations Framework Convention on Climate Change (UNFCCC, 2008) has published more specific information on the methodology of calculating emissions and Assigned Amount Units (AAU).

According to Kyoto Protocol (UN, 1998), GHG includes carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulfur hexafluoride (SF_6). States that ratified the Kyoto Protocol are bound to lower these emissions within their territories.

However, the use of flexible mechanisms were enabled, based upon which the involved states are permitted to lower emissions within the territory of *another* state, or given the option to purchase the right to release emissions of GHG above the stipulated amount *from* another state. Three basic flexible mechanisms exist: International Emission Trading (IET), Joint Implementation (JI) and Clean Development Mechanism (CDM). However, these mechanisms should primarily be used as supplemental methods for lowering GHG emissions.

Emissions-trading is performed using AAU. These units of allotted amounts represent a tradable right for a state to release GHG emissions, expressed as the equivalent of CO_2 (CO_{2-eq}), during the 2008-2012 period. 1 unit of AAU equals 1 ton of CO_{2-eq}. States that fulfilled their obligations are therefore able to sell their excess rights other states participating in the IET.

In order that sales of used AAU not threaten the environmental integrity of IET, participating states joined the Green Investment Scheme, worldwide. The Green Investment Scheme is a voluntary initiative among countries, within which the selling country is obliged to invest those funds gained through the sale of AAU into measures that will, in a provable and measurable manner, lead to the lowering of GHG emission or finance policies and programmes aimed at environmental protection and climate protection.

However, establishing a Green Investment Scheme in a given country increased interest in trading their AAUs, as in the case of the Czech Republic.

5.2 Development in Eastern European countries

Due to the restructuring of their industries in the 1990's, Central and Eastern Europe states found themselves in acceptable situations from the perspective of their obligations to reduce emissions, because they met the goals established through the Kyoto Protocol (UN, 1998) and were able to sell the variance between actual reduction of Green house gases (GHG) emissions within international emissions trading (IET). As of 2010, the Czech Republic had reduced its GHG emissions by 29%, compared to 1990 (EEA Report, 2012). That met the reduction amount specified by the Kyoto protocol, for transfer to another state using the IET.

The goals for reduced emissions within the Kyoto Protocol and the reductions achieved by 2012 among the ratifying states that met these goals (and joined the Green Investment Scheme), are apparent from Figure 6.

From 1990, the year to which the emission comparison is related, environmental protection within the Czech Republic improved considerably by implementing environmental legislation as well as structural changes as the national economy transitioned to a market economy. This resulted in a decrease of heavy-industries and thus the reduction of emissions of GHG as well as other pollutants. These reductions were particular to the countries of Central and Eastern Europe.

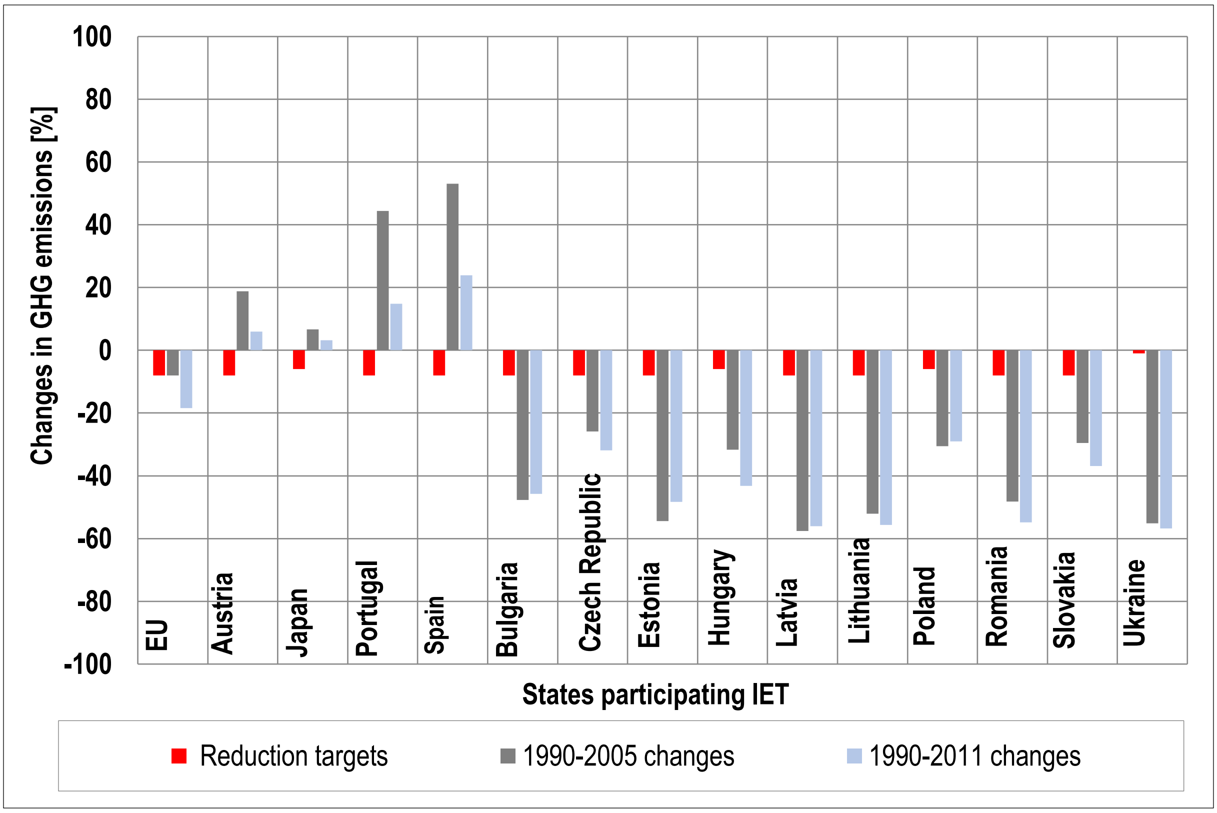


Figure 6: Reduction targets and changes in GHG emission for the states participating IET.
Source: *(UN, 1998)*; *(UNFCCC, 2008)* and *(EEA, 2011)*.

While more developed economies (e.g. Austria, Japan, Portugal, Spain) had problems meeting their Kyoto protocol obligations, the countries of Central and Eastern Europe, due to the restructuring of their economies and transition from heavy-industry toward manufacturing and services, achieved extensive reserves in fulfilling their targets.

5.3 Green Investment Scheme within the Czech Republic

The Czech Republic used its funds from the sale of Assigned Amount Units (AAUs) to create the Green Savings Programme (further as the Programme), the rules of which were set according to the Green Investment Scheme. Its goal was the reduction of GHG emissions thanks to lowering energy use by insulations in buildings and supporting renewable energy sources (RES) intended for heating. 1 unit of AAU equals 1 ton of $CO_{2\text{-eq}}$.

Within the scope of the Kyoto Protocol for the period of 2008-2012, the Czech Republic was forecast to have an emission excess in the amount of approximately 150 million tons of $CO_{2\text{-eq}}$, (Tuerk, et al., 2010). Of this, 103 million was traded in AAUs within the IET between 2009 and 2012, yielding 815 million EUR

(SEF, 2013). The Czech Republic thus ranked among the most successful sellers of AAU worldwide, given the amount of its AAU reserves and the methods by which it used trading.

The Programme focused primarily on supporting the insulation of buildings intended for permanent residence, as well as the use of RES for space and water heating in households, because households offered a significant potential in GHG emission reduction. The Programme subsidized the insulation of family houses and apartment buildings, exchange of non-ecological sources of heat (using fossil fuels) for low-emission sources using biomass and effective heat pumps. The Programme also supported installing biomass boilers and heat pumps in low-energy-requirement new buildings, using solar systems for heating water and providing supplemental heat, including construction of buildings in the passive energy standard.

The subsidy support from the Programme was set up in such way that the funds could be used over the course of the entire Programme, from its launch in April 2009 until the end of 2013. Along with the reduction of GHG, a further positive effect was the support of entrepreneurs, an increase in quality of living and decreasing local air pollution.

5.4 Study on the Green Investment Scheme in the Czech Republic

The study of the Green Investment Scheme in the Czech Republic focuses on evaluating economic and environmental results and finding effective solutions for future projects that aim to reduce GHG emissions and increase energy efficiency. Current results from the Programme 2009-2013 were evaluated, using selected indicators. This evaluation targeted the reduction of GHG emissions, use of financial funds and economic payback for measures in individual subsidy categories.

Furthermore, a comparison of results was provided with similar subsidy programmes in the Czech Republic (e.g. OP Environment). The result of the study is a proposal for effective solutions that could, in future, replace the current New Green Savings Program. The experience from applying the Programme in the Czech Republic is also valuable when establishing similar projects to increase the energy efficiency of buildings that are particularly expected in Eastern European and Central Asian countries. The Green Investment Scheme in the Czech Republic has not yet been evaluated in terms of indicators that would shed light on the economic and environmental impacts of individual types of measures toward the future setup of an optimal package.

The primary data for calculating indicators came from the IS GIS (Information System of the Green Investment Scheme) of the Programme, from the period at the beginning May 1, 2009 through June 30,

2013. It was provided by the State Environmental Fund of the Czech Republic. Secondary data came out of the individual work.

The basic data originated in a data-set tracking the reduction of CO_2 emissions and energy consumption, along with production of energy from RES. Also included are the amounts of subsidies, investment costs, original source of heating in the subsidized buildings, as well as the conditions and areas of subsidy for individual applications. From a total of 80,691applications, It was selected 72,881 that met predetermined criteria. The basic criteria required applications to be paid out, information in the database to be complete and the data in individual applications to have no apparent errors.

Thus selected data was statistically evaluated and used for the calculation of overall reduction of CO_2 emissions, according to a method stipulated by the Programme (Honzík, et al., 2013); total reduction in energy consumption, total investment costs and total amount of subsidy. Only paid out applications in which actual investment costs were known for the period 2009-2013, including the value-added tax (VAT), were included in the evaluation. To achieve objectivity, evaluations of overall results were divided into individual subsidy categories: insulation, low-energy construction, biomass boilers, solar-thermal system and heat pumps. Emission and economic indicators were also calculated for these categories. The economic indicators of return on investment and IRR (Internal Rate of Return) were only calculated from applications for the reconstruction of existing buildings, because there was no relevant comparable data available for new construction.

The costs of fuels and energy were particularly used as secondary data to calculate economic returns. This data was used by an original analysis of prices of the individual types of fuels in the Czech market and from the GEMIS 4.8 database. Calculations of indicators are based on the expected lifespan of the measure being 15 years, although particularly in the area of insulation, the lifespan of the measure is expected to be far longer.

5.5 The outcomes of the Green Investment Scheme

The basic outcomes of the Programme are decreases in energy consumption for space and water heating and a related reduction of CO_2. Decreased energy consumption in buildings primarily contributed to the reduction of emissions, followed by biomass boilers and heat pumps. Table 2 shows a clear overview of investment costs, subsidies provided, emission reduction and savings in energy consumption for space and hot water heating across the individual subsidy areas of the Programme.

Table 2 – Includes basic outputs of the statistical evaluation of paid-out applications – total amounts of investment costs, paid-out subsidies, emission reduction and savings on space and hot water heating for the individual basic categories. Data sources: Report from the IS GIS database. (SEF, 2013).

Table 2: Overview of Green Investment Scheme, Green to Savings.

Subsidy categories	Investment costs [thousands EUR]	Subsidy [thousands EUR]	CO_2 emission reduction [t]	Savings in heating energy [MWh]
Insulation	1,035,854	688,724	7,485,540	1,491,971
Low energy houses	33,072	6,123	22,476	0
Biomass boilers	53,169	32,812	2,646,885	381,908
Solar thermal systems	89,364	53,183	430,351	61,058
Heat Pumps	47,596	13,690	1,179,897	103,317
TOTAL	1,259,055	794,531	11,765,150	2,038,254

Source: (Karásek & Pavlica, 2016).

The ratios of the individual areas to the total number of applications and the total amount of financial subsidy are shown in Figure 7.

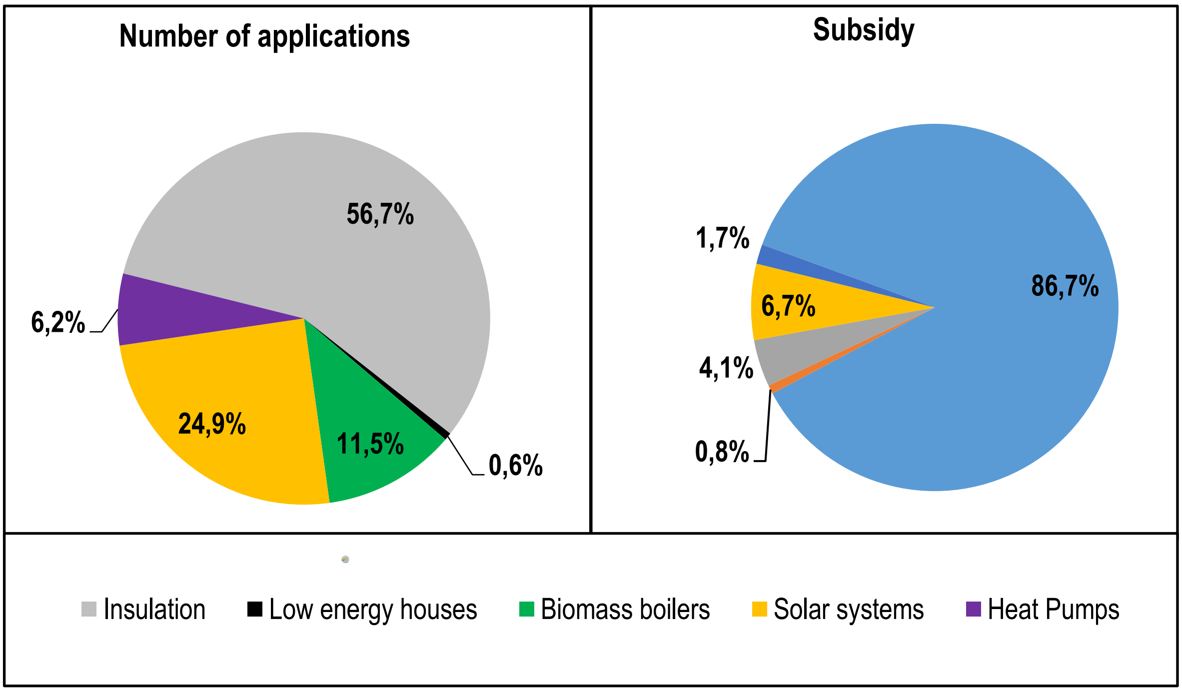


Figure 7: The shares of individual subsidy areas in application numbers and subsidy.
Source: (Karásek & Pavlica, 2016).

5.6 Economic aspects of subsidy

Relationships between share of subsidy and number of applications for individual areas are expressed by the average amount of provided subsidy per application. Specific amounts of subsidies for individual areas are shown in Figure 8. Differences in subsidy corresponds to total investment costs, based on which subsidy was established and which are lower in RES.

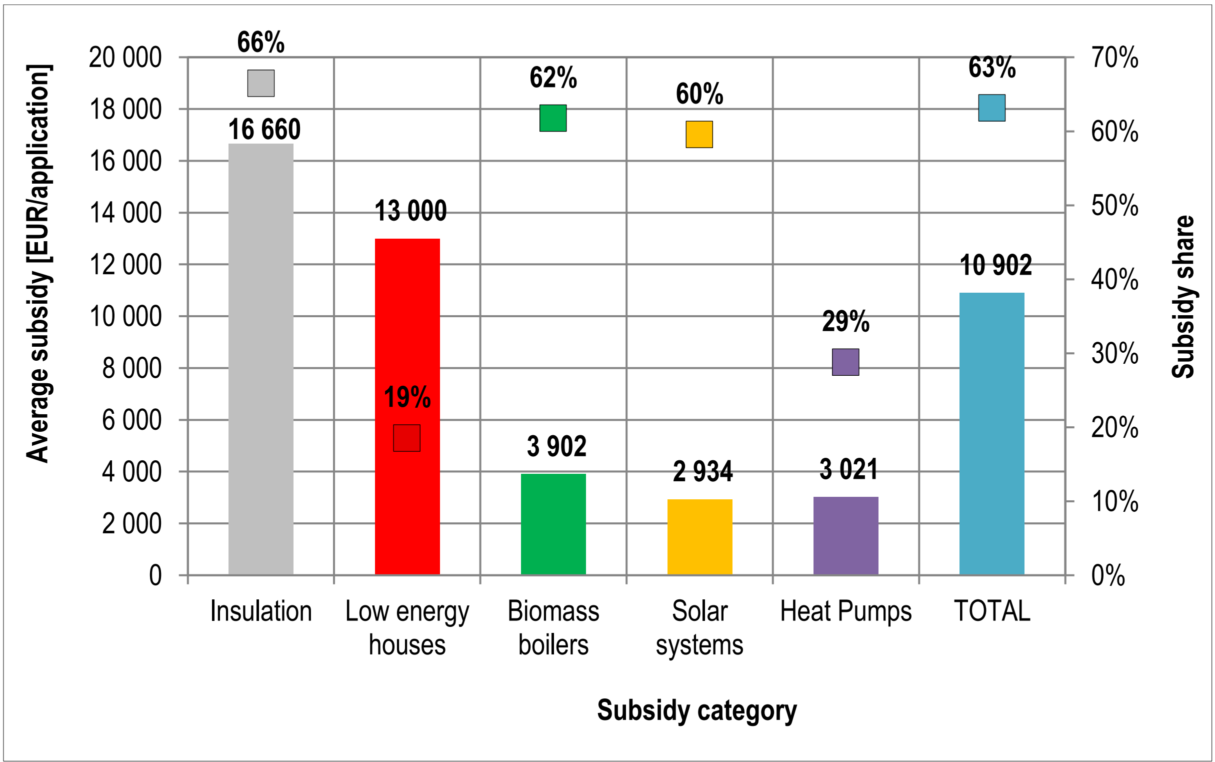


Figure 8: The shares of individual subsidy areas in application numbers and subsidy.
Source: (Karásek & Pavlica, 2016).

The average share of subsidy for all paid-out applications was 63.1% (see Figure 9). This high a subsidy prompted owners of houses to greater interest in the energy-efficiency of buildings and, concurrently, enabled a timely pay-out of the Programme funds.

5.7 Optimum subsidy share

The subsidy share against total investment costs is shown as a percent of the total investment costs. Subsidy share significantly influences the Programme activity. In the Czech Republic, the threshold subsidy level appears to be 20% of the applicable costs (Personal consulting with applicants, 2010-2012). Should the subsidy fall below this level, applicants see no point in handling the rather complicated administration of the project within the subsidy title. Concurrently, in terms of smaller measures, there is competition from the so-called gray economy, where works avoid accounting. This damages the state and lowers the quality of those measures, although at the same time this lowers purchase costs.

The Programme showed significantly higher average subsidy shares. The reason was initially the disinterest of applicants during the first approval round, where only four applications were approved (SEF, 2013). Only changes to the Programme, with an average subsidy share over 50% headed the Programme toward the desired use of available funding.

The later New Green Savings Programme 2013 responded to the current use of funds with a maximum cap amount of 50% toward applicable costs. Thus it was possible to finance more measures with comparable funds allocated in the Programme.

5.8 The Assessment of CO_2 reduction effectiveness

A key aspect of the Program outcomes is reduction of CO_2 emissions because reduced emissions are declared to AAU purchasers. Emission reduction was the basis for calculating abatement cost and greening-ratio indicators. Within the expected lifespan of 15 years, the total reduction of CO_2 emissions was calculated at 11,765,150 tons. The structure shared by individual subsidy areas in CO_2emissions reduction is captured in Figure 9.

The RES area contributed to 36.2% reduction and this was primarily thanks to biomass boilers (22.5%). Given the setup of the subsidy characteristic (replacement of fossil fuels that have a very high emission factor) this was a very effective area. To the contrary, the share of passive housing construction was negligible (0.2%). It is also important that the current successor program, New Green Savings Program, is focused on these measures, due to a need for developing low-energy construction. The structure shared by individual subsidy areas in CO_2 emissions reduction is captured in Figure 9.

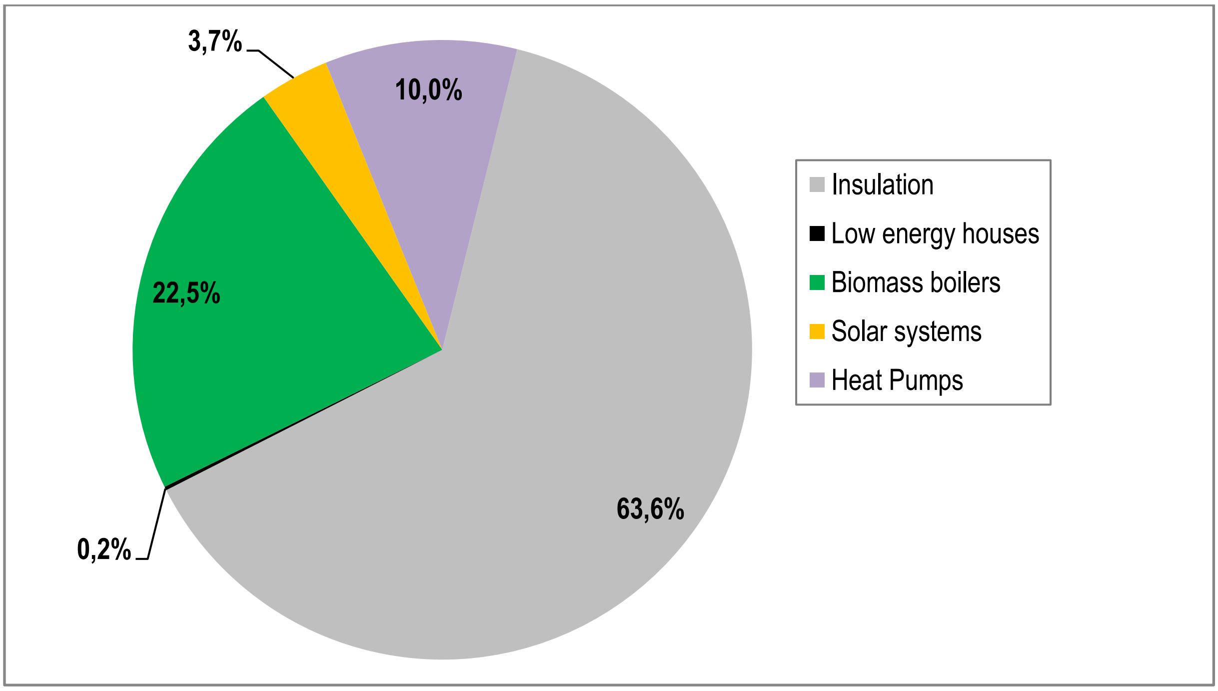


Figure 9: CO_2 emission reduction by individual subsidy categories.
Source: (Karásek & Pavlica, 2016).

5.9 Abatement cost and Greening ratio evaluations

The most effective emission reduction comes from biomass boilers and heat pumps. The least effective area was passive energy building standards. The values of price of emission reduction for individual subsidy categories of the Program are shown in Figure 10. By comparison, the graph in this figure identifies measurable costs of reduction in terms of subsidies, as well as total investment costs.

AAUs were most effectively used in areas of biomass boilers and heat pumps with highest greening ratios (see Figure 11).

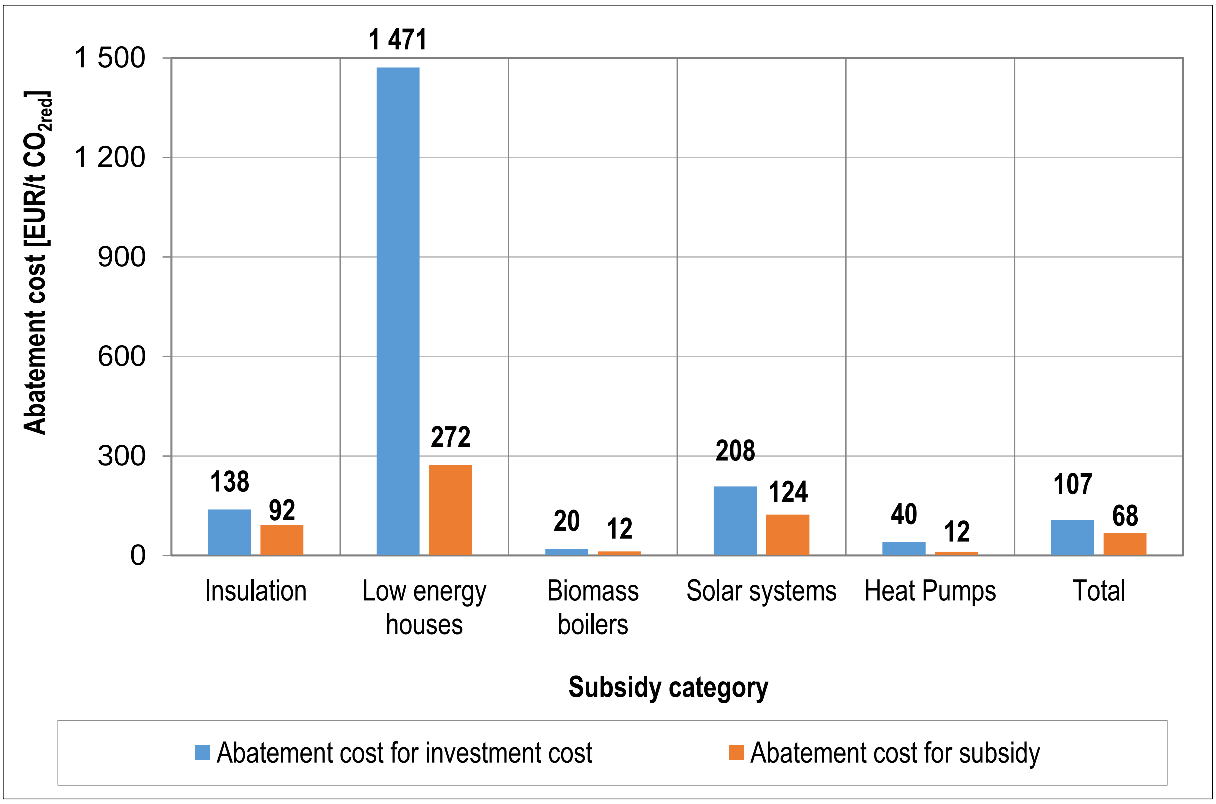


Figure 10: Abatement costs for individual subsidy categories.
Source: (Karásek & Pavlica, 2016).

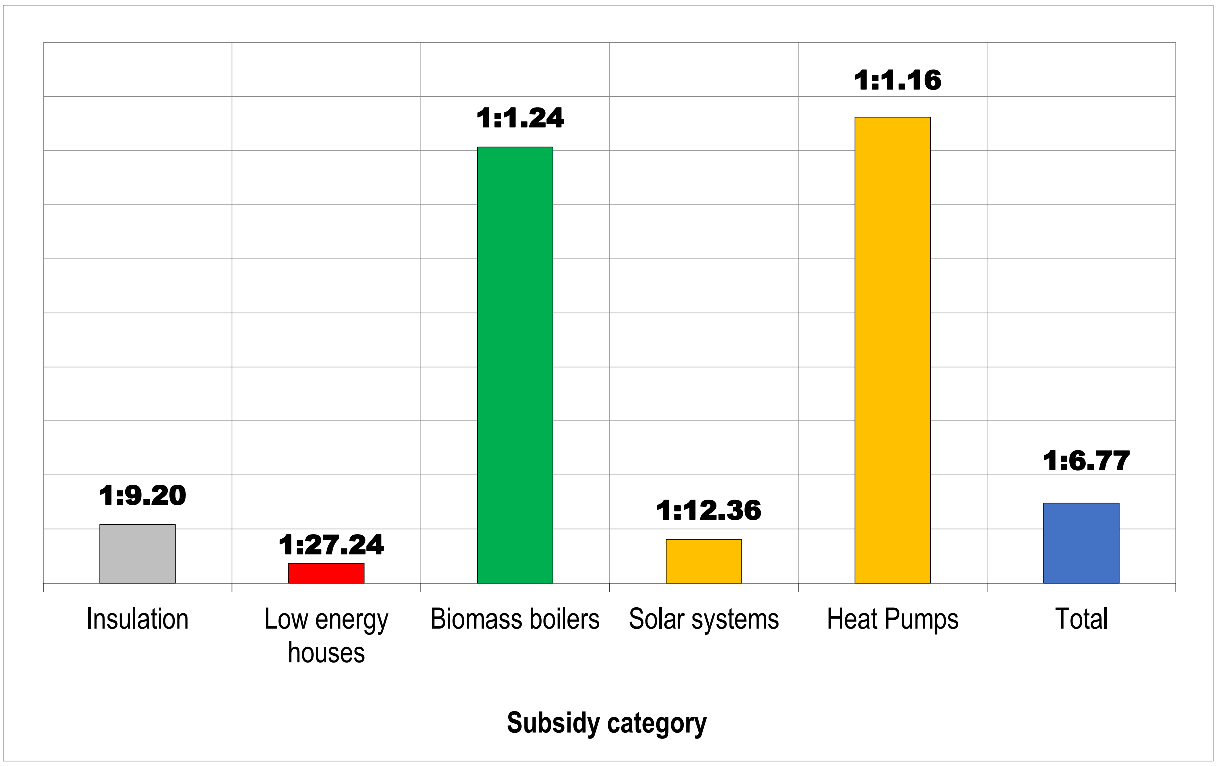


Figure 11: Greening ratios for individual subsidy areas.
Source: (Karásek & Pavlica, 2016)

Figure 9 shows a clear comparison overview of individual areas of subsidy, using the shares of paid-out application, investment costs, paid-out support and reductions of CO_2 emissions. The difference in these shares of individual subsidy areas is apparent at first glance. Insulation dominates in terms of number of applications, followed by solar systems. For investment costs and paid-out subsidies, the share of insulation grows and the share of RES is very small. The share of reduced emissions is notable, as the importance of biomass boilers grows (22%). This indicates the significance of using biomass in place of fossil fuels. To the contrary, the importance of solar systems is negligible in reducing emissions.

5.10 Assessing economic payback periods

Evaluation of economic return was based on savings in heating energy. Energy savings related to building energy consumption in its original condition and after implementing the measure (for example insulation). In RES, heating savings arose from the energy produced by these systems. Figure 7 shows the result of the economic PP for the individual subsidy categories.

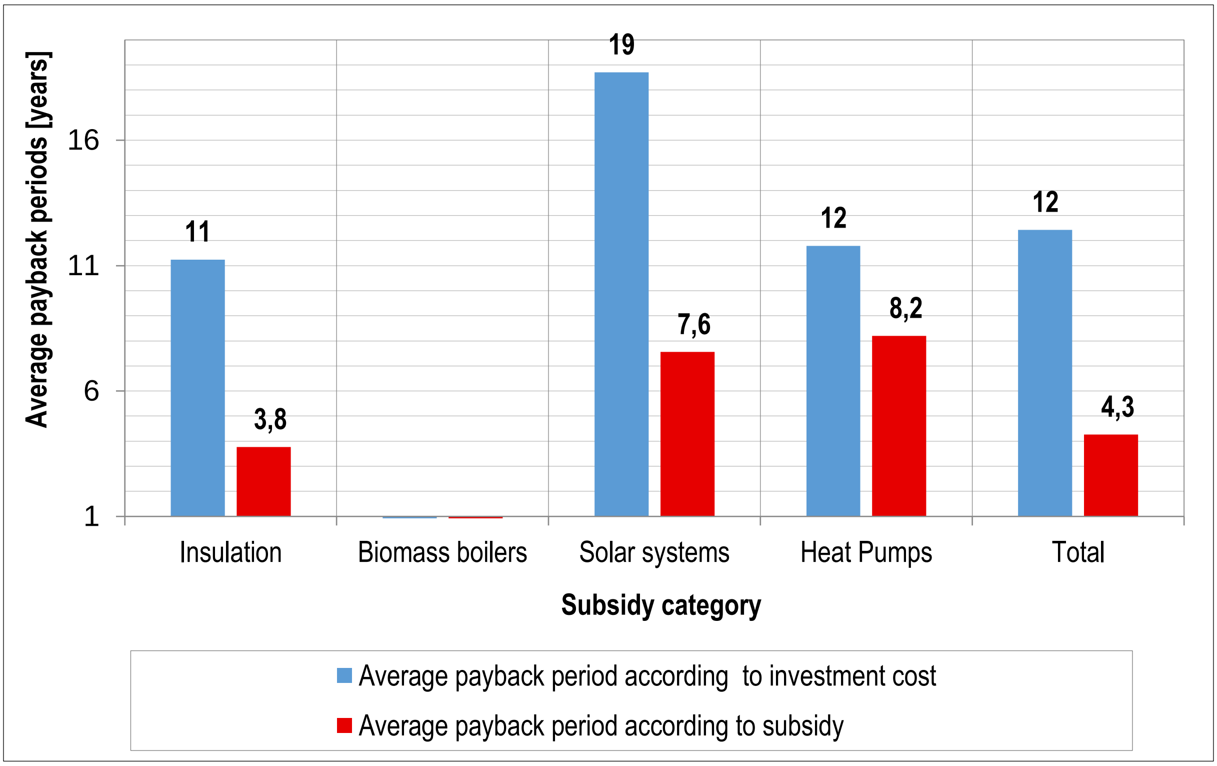


Figure 12: Economic payback period for individual subsidy categories.
Source: (Karásek & Pavlica, 2016).

Notes: The applications without payback periods were excluded from the calculation.

The construction in passive energy was not included in the economic evaluation, given the small number of applications and because these were new buildings, hence it was impossible to calculate realistic energy savings.

For biomass boilers category, this was generally not a return on investment, because these were cases of transferring from fossil fuels (coal) to heating using pellets that have a considerably higher purchase price. For this reason, the ratio of expended investments and savings on heating costs was negative. This phenomenon was not applicable in terms of replacing heating with electricity, or possibly brown coal.

A more detailed interpretation of the outputs of economic return for the individual categories of subsidy is shown in Figure 13.

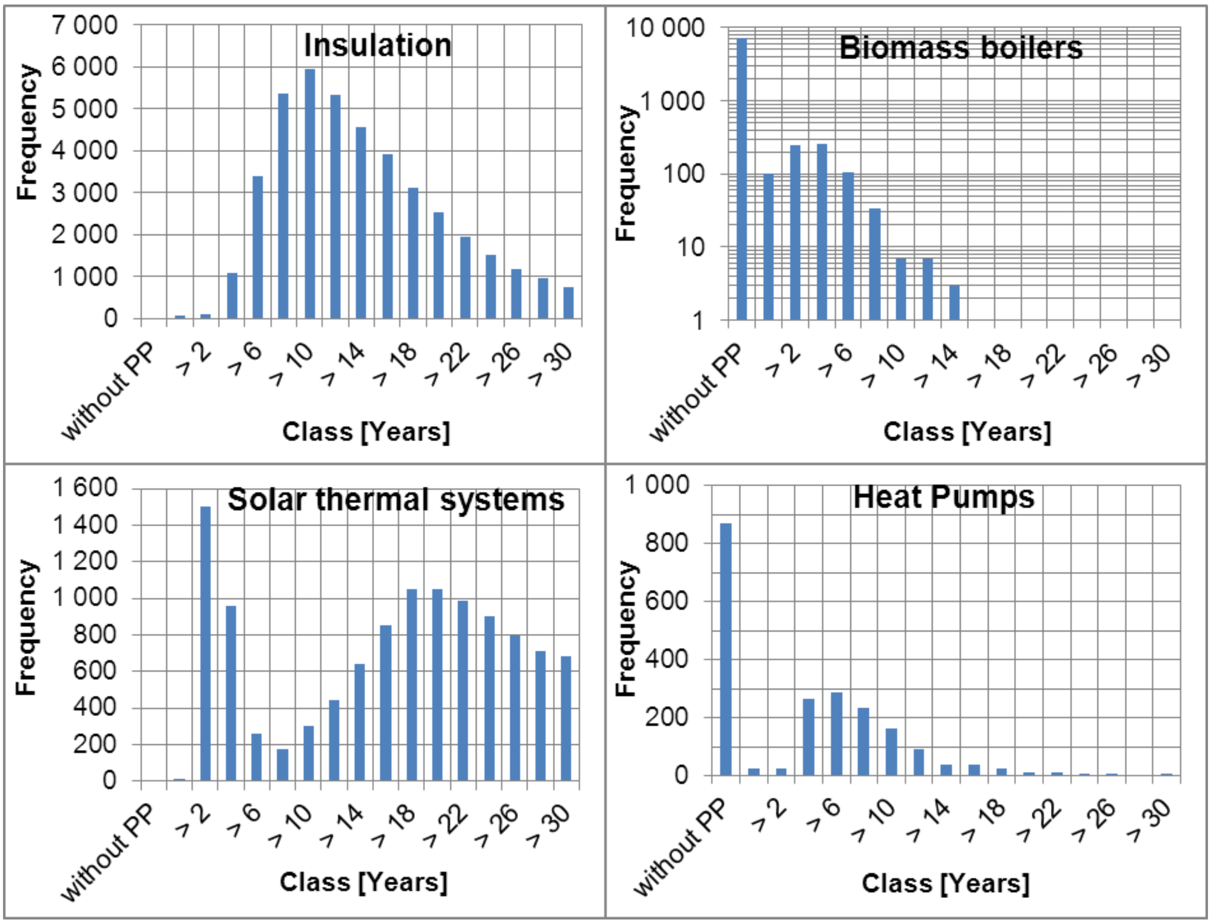


Figure 13: Histograms of economic payback periods for insulation, biomass boilers, heat pumps and solar thermal systems.

Source: (Karásek & Pavlica, 2016).

5.11 Frequency distribution of economic payback periods

Simple economic paybacks for reconstruction projects, without considering the user subsidy, were analyzed in detail and subsequently interpreted in the form of histograms within this study. The large variation in payback indicates it’s significantly influenced by local conditions, specific technical solutions and, in particular, the shape complexity of the building. A further influence is the variability of calculating methods for energy savings in the application evaluations. A total of 41,341 projects were evaluated from the perspective of simple payback in the area of family houses and apartment buildings.

In terms of economic evaluation in the RES category, it appears the critical aspect is the fuel used for heating, before and after implementation of the measure. When replacing solid fuels with biomass or a heat-pump, there is no payback to the investment but, to the contrary, an increase in negative cash flow. Therefore, such measures have no financial benefit for the user and benefits accrue more in environmental aspects and increased comfort. This is particularly true for older small boilers using solid fuels, usually manually operated and requiring more frequent tending.

Shorter payback periods were achieved when replacing electricity. The high cost of electricity (104 €·MWh^{-1}) has an essential impact on positive cash flow over a longer period of time. The cost of fuel thus significantly influences simple payback of the measure. The shortest payback period was achieved by replacing electricity. To the contrary, projects in which heating with solid fuels are generally replaced have the longest payback periods. The costs of fuels used for space and water heating (that were replaced) are shown in Table 3.

Table 3: Prices of energy for heating, replaced or newly used in projects analyzed, applicable in the Czech Republic within the period of the Program duration.

Type of Energy for Heating		Price of Energy for Heating [EUR·MWh^{-1}]
Replaced heating energy	Coal	24.4
	Natural Gas	61.2
	Liquid fuels	132
	Electricity	104
	Central heating supply	80.8
	the Rest	78
RES for heating	Biomass (70 % pellets; 30 % logs)	40.4
	Sun Energy	0
	Electricity within Heat Pumps	34.7

Source: (Karásek & Pavlica, 2016)

A total of 7,973 projects in biomass boilers were evaluated economically, of which 7,214 failed to show a simple payback. This was because only projects implemented in existing buildings were evaluated, quite often replacing brown coal that is cheaper than biomass and in tandem with the operation of a heat pump. A logarithmic scale was used to display payback ratios (see Figure 13).

A total of 2,107 heat pump installations were evaluated, of which 1,236 indicate simple payback. The number of projects analyzed is considerably lower compared to other areas, because heat pumps are usually installed in newly built buildings and new building projects were not included in the economic analysis. Other projects replaced cheaper solid fuels (24 €·MWh^{-1}) with more expensive electricity by heat pumps (35 €·MWh^{-1}) and thus failed to show simple payback.

A total of 11,321 solar thermal projects were evaluated, of which, with one exception, all indicated simple payback. Longer simple payback periods are also influenced by the fact that solar thermal systems cover the heating of hot water and their ratio for covering space heating is low. A considerably shorter payback period was achieved in installations in apartment buildings where the median of simple payback was 6 years.

As is apparent from the results, when establishing the parameters of subsidy programmes, the type of replaced fuel is paramount. Goals of reconstruction projects should generally be focused on replacing electricity as the energy source in family houses and apartment buildings, with its higher consumption of energy for heating. The question is, whether the replacement of electricity should not rather be shaped by state regulation, in the form of an obligation. Positive impacts on the environment and the economy would be very significant.

However, this trend would be in direct contradiction with projects supported in past times, when the effort was directed primarily at limiting pollution from local heating sources. Replacing coal has a large significance primarily from an environmental point of view, however, should the costs of fossil fuels fail to include the externalities or emission tax, their replacement with biomass will not be economically effective.

5.12 Brief description and comparison of other significant environmental programmes

To provide a complete evaluation, the results of other significant programmes also focusing on the reduction of GHG emissions that were applied in the Czech Republic in the years 2007-2013 were included. Besides the above analyzed Green Savings Programme, the following programmes were consider as significant:

- The Operational Programme (OP) Environment–Priority axis 3.1 and 3.2 (administered by the State Environmental Fund)
- Programme EKO-ENERGIE (administered by Ministry of Industry and Trade of the Czech Republic) –this programme is only focused on insulation.

Based on the study performed by the SEVEn company (Honzík et al., 2013), it was prepared a comparison indicator of abatement costs from the perspective of the subsidy provided for individual RES technologies and insulation for the above stated programmes (see Figure 14). Data for 419 projects from the OP Environment (18 projects of insulation, 64 biomass boilers, 81 solar thermal systems and 256 heat pumps) and data from the EKO-Energie program for 548 applications were processed. More detailed information on comparison of programs is available in the study published by SEVEn (Honzík et al., 2013).

As is apparent from a mutual comparison, from the perspective of effectiveness of paid-out subsidy, the Green Savings Program is more effective in reducing GHG emissions than the OP Environment. To the contrary, the EKO-Energie program shows much higher effectiveness in the use of financial funds, as confirmed by the values of the abatement cost indicator, which are 5-times lower than the Green Savings Program and 9-times lower than the OP Environment. This fact is caused by their lower share of the subsidy in the investment costs that were, on average, 32%. The average share of subsidy in the investment cost in the Environment was 63% and 89% in the case of OP Environment.

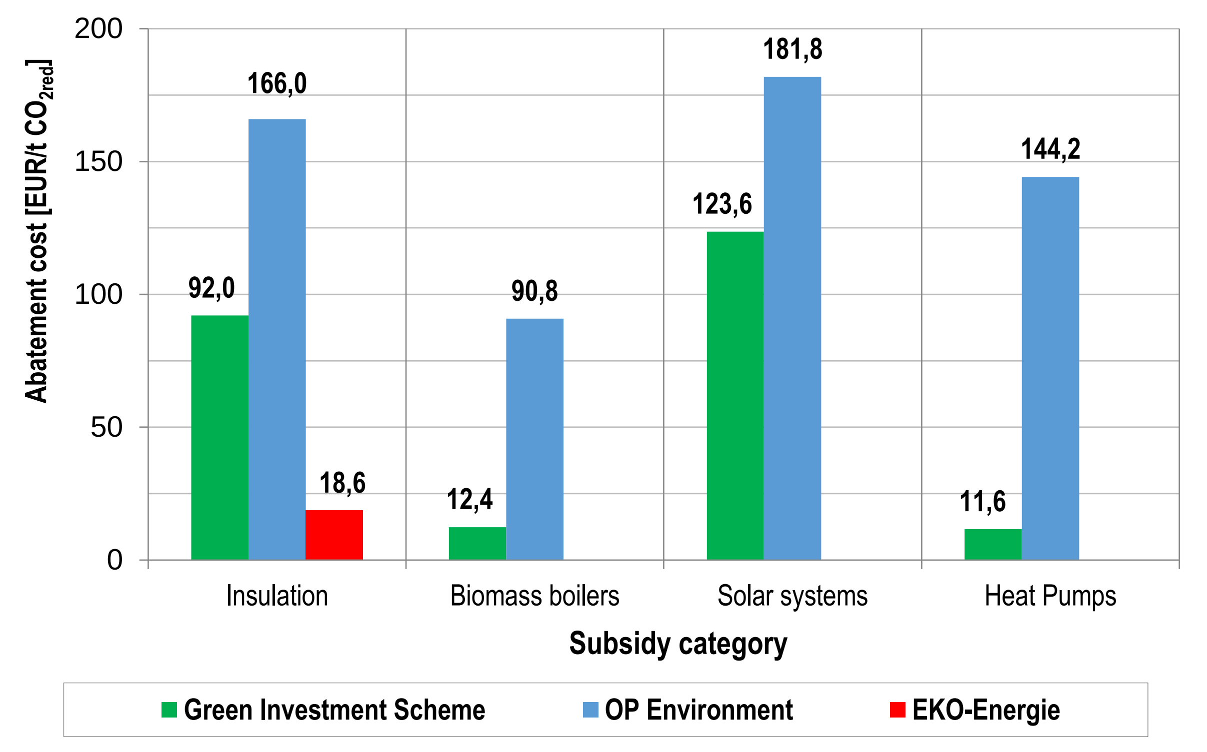


Figure 14: The Comparison of Subsidy abatement costs within three different subsidy programmes running in the Czech Republic.
Source: (Karásek & Pavlica, 2016).

Note: RES technologies were not supported within EKO-Energie programme.

5.13 Overall assessment

Abatement costs and greening ratio indicators were selected as the evaluation parameters for the Environment, thanks to which it was possible to formulate the effectiveness of the relation between the paid-out subsidy and the reduction of CO_2 emissions. The statistical evaluation of the received data was processed into graphs expressing the results of the indicators for individual subsidy areas. In the end, a final evaluation was performed, identifying the best of the subsidized solutions from the perspective of economy and effectiveness of GHG emission reduction (see Table 4).

The output of the indicators clearly shows the effectiveness of supporting biomass boilers and heat pumps for reducing emissions. The subsidy for insulation is less effective in relation to emissions. Solar thermal systems and construction in passive energy standards have low effectiveness in reduction of emissions and it is necessary to focus on the setting of an optimum amount of their subsidy.

The decrease of costs for emission reduction and increased effectiveness by using financial funds raised through AAU sales may be achieved by a suitable setup of the amount of subsidy according to analysis of investment costs. We consider the value 1:1 for a greening ratio to be optimal. Based on this value we can state that only the support of biomass boilers and heat pumps fulfilled its purpose. To the contrary, the installation of solar systems and systems for reduction of energy consumption (insulation) should be reduced.

Table 4: Summary of results of the Programme. The resulting values of key indicators for the individual areas of subsidy.

Subsidy Area	Abatement cost [€·t CO_2^{-1}]	Greening Ratio	Payback period [y]	Payback period incl. subsidy [y]	Number of applications Total/Economy Assessed
Insulation	92.0	1:9.21	11.2	3.8	41,341/41,341
Low energy house	272.4	1:27.24	NA	NA	
Biomass boilers	12.4	1:1.24	WROI	WROI	8,408/7,566
Solar thermal systems	123.6	1:12.62	18.7	7.6	18,129/15,398
Heat Pump	11.6	1:1.25	11.8	8.2	4,532/1,990
Total	67.5	1:6.77	12.4	4.3	72,881/66,293

NA = Non analyzed

WROI = Without return on investment

Source: (Karásek & Pavlica, 2016).

6 Case study on ex-post evaluation of Green Investment Scheme

The case study was carried out as part of the site visits (2012-2014) of the Green Investment Scheme in the Czech Republic conducted by the author and its evaluation in 2017. Later it was published in WENE Energy and Environment journal as (Valentová, et al., 2018)

6.1 Introduction

As the buildings consume about 40 % of energy in developed countries and about 75 % of buildings in EU MS are considered as insufficient in terms of energy efficiency, there is still a huge potential for improvement of the buildings stock and decrease of energy consumption. Many supporting schemes in terms of EU operational programmes or programmes at the national level have been set up, however the pace of improvement is still not high enough.

There has been a vast amount of literature on the expected outcomes of various energy efficiency, renewable energy sources (RES), and greenhouse gas (GHG) emission schemes and programmes. However, the level of detail and accuracy of the monitoring system of the programmes varies greatly and furthermore, the number of ex post evaluations of the real outcomes of such programmes is still inadequate, especially in smaller scale projects (Sayeg & Bray, 2012). Monitoring of achieved energy savings is not usually implemented and comparative studies on ex post evaluation are still missing. The current text therefore contributes in this field by covering ex post evaluation of large variability of measures, including behavioural aspect of energy consumption (Carley & Browne, 2013), (Clinch & Healy, 2001), (Den, et al., 2016), (Webber, et al., 2015).

The study evaluates the outcomes of the Green Savings programme. Based on evaluation of ex post inspections which took place towards the end of the programme, it analyses to what extent the expected energy savings from the subsidized projects turned into actual energy and emission reductions. Furthermore, based on the inspections combined with qualitative interviews with the applicants, it analyses and discusses the reasons behind the differences in ex-ante and ex-post evaluations. The study therefore contributes to the current academic debate by providing a thorough insight in the real outcomes of the Green Savings programme. The results of the ex-post inspections offer a valuable input in future design of programmes as well as evaluations of other, similar policy measures.

The subsequent sections are structured as follows: The second section presents the Green Savings Programme including the main outcomes of the programme, types of applicants and measures. It is then followed by methodological section, which describes organization of the inspections, the methods for data acquisition and indicates the logic behind the calculation of CO_2 emission savings. In the fourth section, the main results of the inspections are presented. The section provides an insight in quantitative results and reasons behind possible differences between ex ante and ex post calculations. Furthermore, a special focus is placed on the qualitative aspects of the subsidized measures such as social impact on households. The last section concludes and conveys policy implications of the research.

6.2 Green Savings Programme – overview

The Green Investment Scheme (GIS) is an influential tool to reduce greenhouse gas emissions. The states in the GIS are obliged to invest the funds gained through the sale of Assigned Amount Units (AAUs) in GHG emission saving and environmental protection programmes. Under the Kyoto Protocol for the period of 2008 – 2012, the Czech Republic achieved an assumed emissions surplus of about 150 million tons of CO_2 eq. (AAUs). About 100 million AAUs could be traded under the international emission trading mechanism.

The GIS in the Czech Republic has taken then the form of the Green Savings Programme (further also referred to as the Programme) which ran from 2009 to 2012 and supported energy efficiency and renewable energy sources measures in residential buildings. These measures led to an immediate reduction of CO_2 emissions and will kick-start a long-term trend of sustainable construction. The State Environmental Fund of the Czech Republic (SEF) has been entrusted with the management of the Programme.

Calculation of CO_2 reduction was carried out under the Programme. The CO_2 emissions reduction has been achieved by implementing the Green Savings Programme based upon the applications registered, approved and paid until 31 December 2013 across assisted areas. The calculations of CO_2 reduction were provided by SEF, according to a validated calculation method devised for the calculation of CO_2 reduction under the Green Savings Programme.

According to the Annual Report of the Green Savings Programme in 2013, the total number of applications registered under the programme was 74,117. In total, 80,696 projects were registered by the end of 2013 and the overall disbursed subsidy of applications registered by 31 December 2013 exceeded CZK 20.29 billion. Figure 15 shows the distribution of applications across subsidized areas in number of applications (%) and total allocated subsidy (CZK). The total presumed reduction of CO_2 in 2013 reached almost 800,000 tons per year. In total, 73,916 applications were paid by the end of the year.

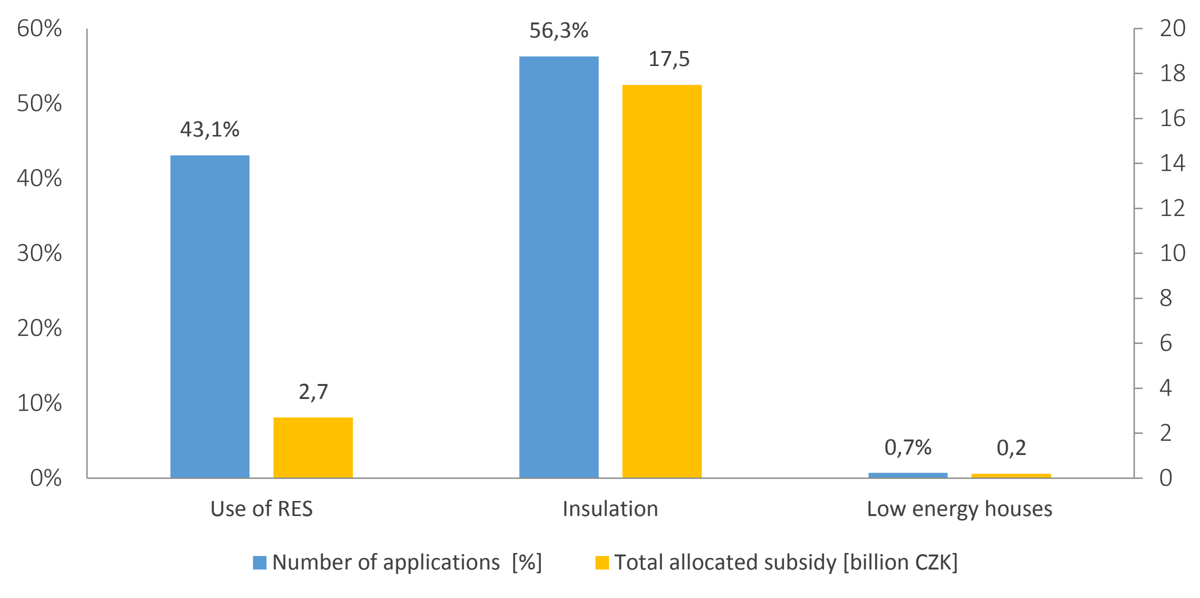


Figure 15: Distribution of applications across supported areas in number of applications (as %) and total allocated subsidy (CZK).
Source: (Karásek & Pavlica, 2016).

By 31st December 2014, most of the projects under the Green Savings Programme 2009 – 2012 already had been provided with the subsidy. The only projects discussed in 2014 (remaining a few hundred projects) were those which showed some technical or administrative defects. According to the information provided by the SEF, all these projects were completed in 2014.

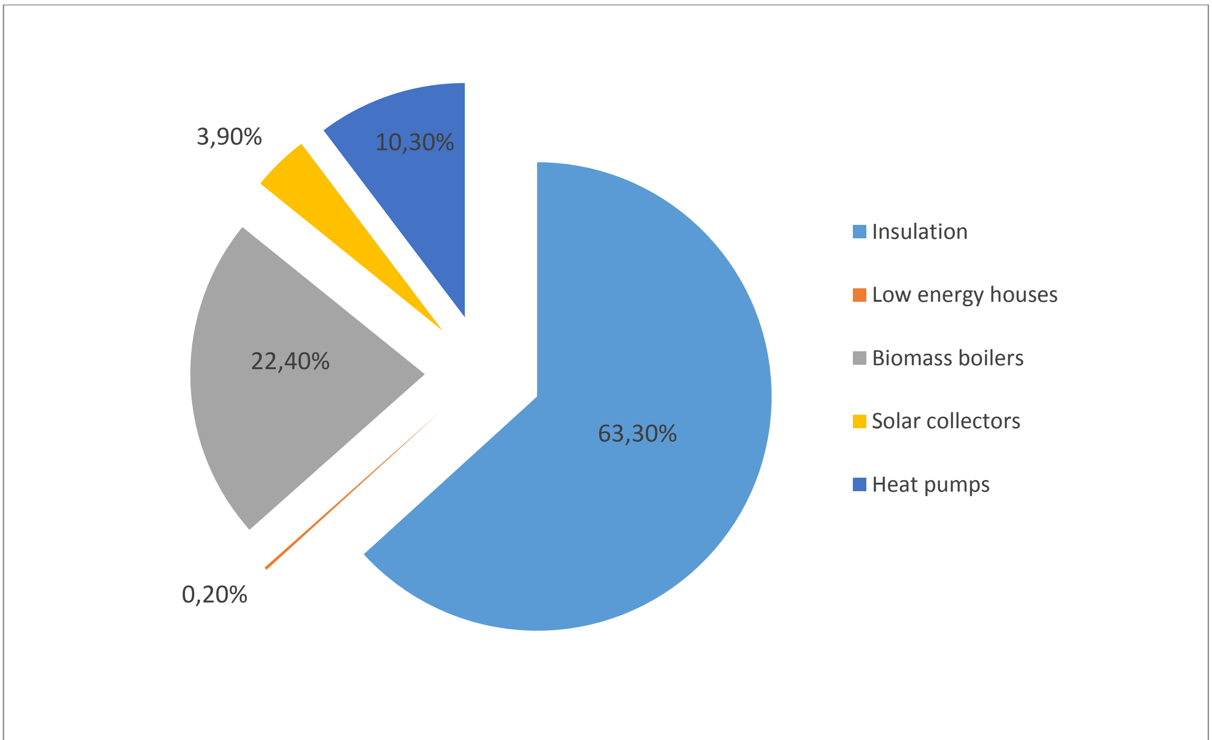


Figure 16: CO2 emission reduction by individual subsidy areas.
Source: (Karásek & Pavlica, 2016).

Within the expected lifespan of 15 years, the total reduction of CO_2 emissions was calculated at 11,765,150 tons. The structure shared by individual subsidy areas in CO_2 emissions reduction is captured in Figure 16. Insulation of the building was the most demanded and implemented measure.

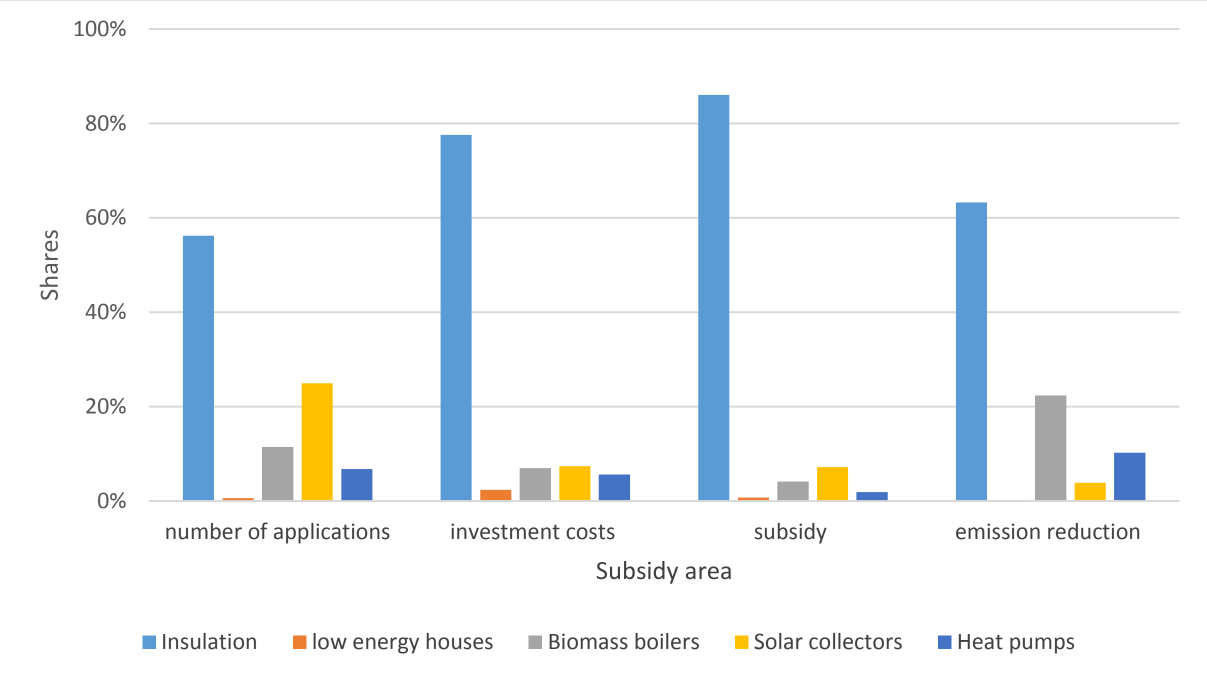


Figure 17: Comparison of subsidy areas via shares on number of applications, investment costs, subsidy and emission reduction.

Source: (Karásek & Pavlica, 2016).

The most effective emission reduction was achieved from biomass boilers and heat pumps. The least effective area was passive energy building standards as the reference consumption is already low. By comparison, the graph in this figure identifies measurable costs of reduction in terms of subsidies, as well as total investment costs. AAUs were most effectively used in areas of biomass boilers and heat pumps with the highest greening ratios (see Figure 17).

6.3 Approach

In 2012, State Environmental Fund, the administration body of the Green Savings Programme, launched a verification procedure of the outcomes of the subsidized projects. Such procedure was a condition set by the buying parties of the AAUs. During this process, total of 206 inspections of energy efficiency measures were carried out to verify the achieved energy and CO_2 emission savings. Often, the applicants bundled energy efficiency measures together (this was also supported by the programme in the form of an additional bonus). Therefore, in 78 cases, two to three inspections were carried out in one site – i.e.

a combination of two to three energy efficiency and RES measures was carried out by a single applicant. In total, 124 projects (applicants) were therefore inspected.

6.4 Preparation of the inspections and sampling

The sample for inspections was selected from a list of applications by the administration body in cooperation with the company carrying out the inspections. Only applications in which the measures were implemented at least 18 months ago were selected. The list of applications contained all relevant data for emission reduction calculations and the calculated CO_2 emission savings. The list was further complemented with specific documentation of selected applications, such as energy savings calculation, project documentation and application for the Programme, to make the inspections more relevant.

The sample reflected both the regional diversity of the projects and the diversity in types of measures. The aim was to cover all 14 regions of the Czech Republic and also to cover sufficiently all of the supported areas (insulation, low-energy houses, biomass boilers, heat pumps and solar-thermal systems). In addition, the inspectors gave special preference to combinations of the measures, i.e. projects in which two to three types of measures were combined. The reason for this was mainly to have better knowledge on these types of projects, which were to be preferred in the future rounds of the programme.

6.5 Inspections

It was decided to carry out direct interviews with the applicants. Two-member teams visited each site-project. Compared with e.g. phone or email interviews, such approach allowed to tailor the questions and lead the interviews with respect to the actual situation at the site and quality of documents provided by the applicants. Such method also allowed to better understand the approach of the applicant and increased the trustworthiness of the results. Furthermore, it has also decreased the administrative burden of the inspections.

On site, the process of inspection went as follows:

- Controlling of the project documents,
- Determination of the real energy consumption before and after implementation of the measures, based on energy invoices (and other relevant available data),
- Compliance check of the implemented measures to the project documentation, photodocumentation,
- Questionnaire on the inspection (in Annex 3).

6.6 Evaluation

After each round of inspections (in total three), a report on the inspections was elaborated containing quantitative and qualitative analyses.

Based on available data (energy invoices), the inspectors further examined the real ex-ante and ex-post energy consumption and compared it with the calculated energy and CO_2 emission savings from the project documentation.

The CO_2 emission savings were calculated as the difference between the CO_2 emissions before and after the implementation of the energy efficiency and RES measures within the Green Savings Programme. The calculation used the general CO_2 emission factors as to Decree No. 425/2004 Coll. The emission factors are summed up in the following (Table 5).

Table 5: General CO_2 emission factors according to Decree No. 425/2004 Coll.

General CO_2 emission factors [t CO_2/MWh calorific value]				
Coal	Light fuel oils	Natural gas	Electricity*	Biomass
0.36	0.26	0.2	1.17	0

* t CO_2/MWh electricity

Hereafter, an example of the calculation of CO_2 emission reduction for individual subsidized measures in the Green Savings Programme is provided. More details on the calculation methods can be found in (Karásek & Pavlica, 2016).

Similarly, the ex-post evaluation was based on the structure of energy carriers consumed in the building and on invoices scanned during the on-site inspections. During the evaluation process, the respective consumption was compared with the ex-ante consumption. According to the energy carrier related CO_2 emission factor was selected (see Table 5) and the CO_2 emission savings were calculated.

In addition, the inspectors carried out qualitative, semi-structured interviews with the applicants in order to examine further relevant factors that may have influenced the final energy consumption in the inspected objects (such as use of the building, thermal comfort, occupancy of the building, additional heat sources, etc.). A discussion with the building owners about the process, initial expectations, duration of construction works, and overall satisfaction was an important part of the interview. The discussion took about 20 minutes and usually brought explanations to the differences in ex ante and ex post evaluation.

6.7 Results and discussion

In total, 206 measures were inspected in 124 objects towards the end of the Programme. In 10 inspections (5 objects), the meeting with the applicant did not happen due to unexpected circumstances on the side of the applicant, therefore, in such cases the verification of the results and implementation of the measures could not be made. However, all 206 inspections are covered in the overall statistics on types of measures and types of buildings, as the measures were carried out.

In the following section, the results of the inspections are analyzed and discussed. Firstly, the general results on the inspections are covered, including structure of the sample of the inspections, overall attained CO_2 emission and energy savings. Then, the methodical and behavioral factors behind the results are discussed. The section concludes with further qualitative aspects of inspections and lessons learnt.

6.8 General data description of the inspections

Roughly three quarters of the inspected buildings were single-family houses, the rest were multi-family (apartment) buildings. Of the single-family houses, one third were newly build houses – all in low-energy standard, as this was the condition of the programme. Of the apartment buildings, half were panel houses (Figure 18).

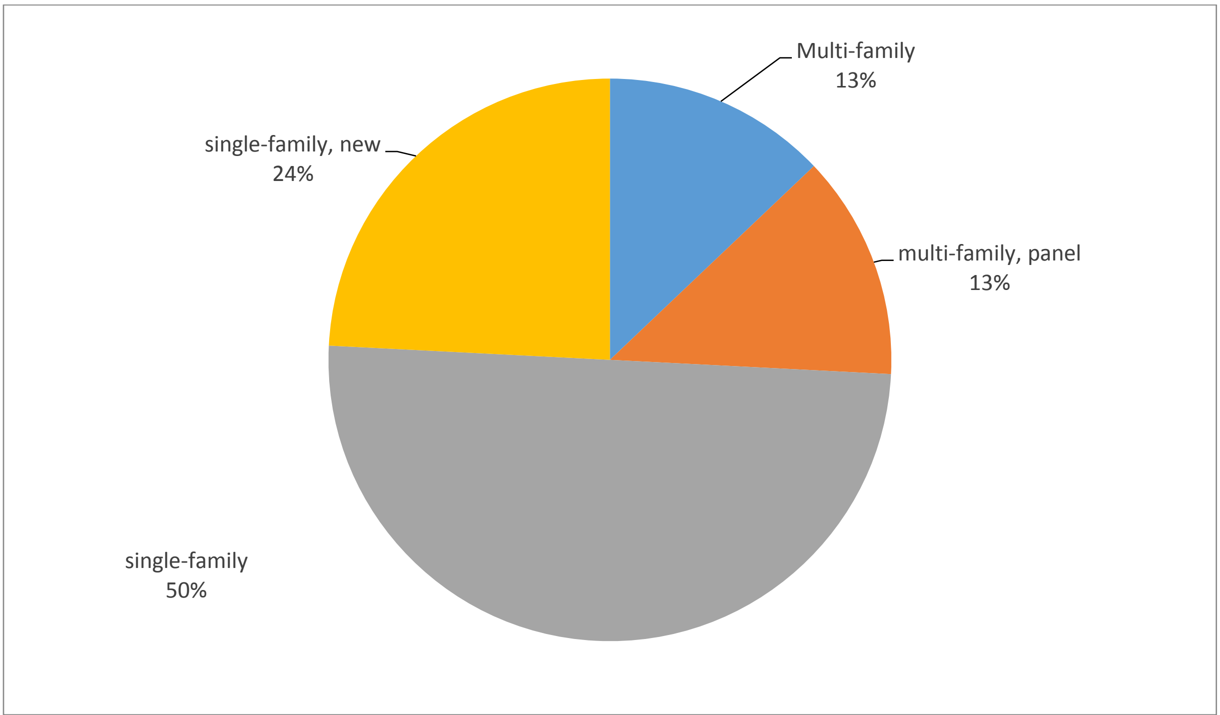


Figure 18: Structure of the inspections according to types of buildings.
Source: (Valentová, et al., 2018).

Over a third of the inspected measures entailed partial or complete thermal insulation of the buildings (Figure 19). While complete thermal insulation, including the whole building envelope, was carried out majorly by multi-family houses, partial thermal insulation was preferred by applicants in single-family houses (75 % of partial insulations in the sample were single family houses). In total, 15 single-family houses in low-energy standard were inspected (7 % of all the inspected measures). Another 17 % of the measures covered installation of a new low-emission biomass boilers (either as a replacement of an old, inefficient boiler, or as a new installation) and in 13 % of the cases heat pumps were installed. 29 % of the measures entailed installation of solar-thermal systems (more than a third only for hot water preparation, 64 % both for hot water preparation and additional heating).

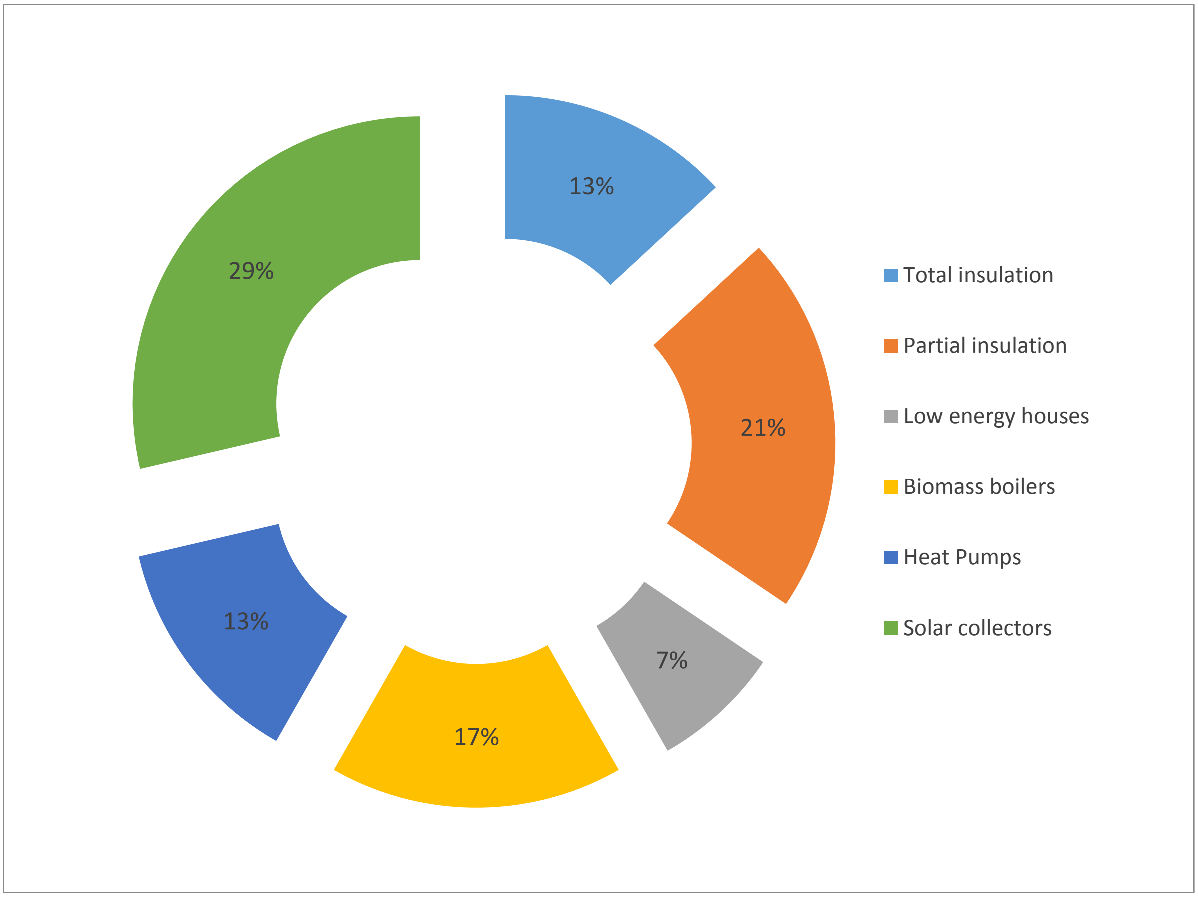


Figure 19: Structure of the inspections according to types of measures.
Source: (Valentová, et al., 2018).

The inspections do not fully copy the structure of measures in the whole programme. For instance, in the inspections, low-energy houses were higher represented than in the whole population (all projects supported by the programme). Conversely, the share of insulation was lower within the inspections, than in the whole programme (cf. Figure 17). The reason for this lies in the approach to the selection of the sample for inspections.

Importantly, in 39 cases the verification of the real attained energy savings could not be performed. The main reasons (apart from the above mentioned 5 cases, during which the inspection did not happen) were mainly twofold: the unavailability of invoices (and irrelevant data provided by the applicants), and low level of detail of the invoices.

Firstly, in about half of the cases, the reason why verification could not be made was that the applicants did not manage to provide the energy invoices from before and/or from after implementation of the measures. Furthermore, sometimes the data provided were actually irrelevant for the calculation of the energy consumption: e.g. the applicant provided the invoice for purchase of natural gas, but no data for actual consumption.

Relatedly, in multi-family buildings, the applicants provided invoices only for selected apartments, not the whole house or all apartments. It was not possible to extrapolate from such data to the whole consumption of the building. Therefore, the calculation could not be made, either.

Secondly, in half of the cases, the invoices for energy (specifically electricity) consumption were available. However, it was impossible to extract the specific data on consumption of heat pumps (or solar-thermal systems, etc.) from the rest of the home appliances. In some inspections, an expert estimate from the consumption in the high and low tariffs were made. However, this was not possible in all the cases and moreover, the level of precision of such calculation may be rather low. In addition, the ex post calculation was not carried out for the newly built (low-energy) houses (15 cases). The invoices were not available as the houses were either not put in use in the time of the inspection yet, or have been in use only for a part of the year. Therefore, only partial invoices would be available and did not allow for the comparison of energy consumption. Furthermore, even if the data was available, the real energy consumption in the building can only be compared to the value of a reference building, due to non-existence of “before measures” data.

The comparison between the ex ante verified and ex post evaluation could therefore be made in 70 objects in total. In 54 of those cases, the ex post CO_2 emission savings were lower than the ex ante values, whereas in 16 cases, the ex post CO_2 emission savings were actually higher than the ex-ante evaluation. Figure 20 shows the histogram of the calculated differences between ex ante and ex post data. On average, the difference between the two values was 25 %, meaning that on average, the ex post data were 25 % lower than the ex ante outcomes as calculated in the project documentation of the applications. The median was 32 %. Figure 20 presents number of applications and its deviation from the calculated energy savings. The left columns introduce application with higher achieved energy savings than calculated.

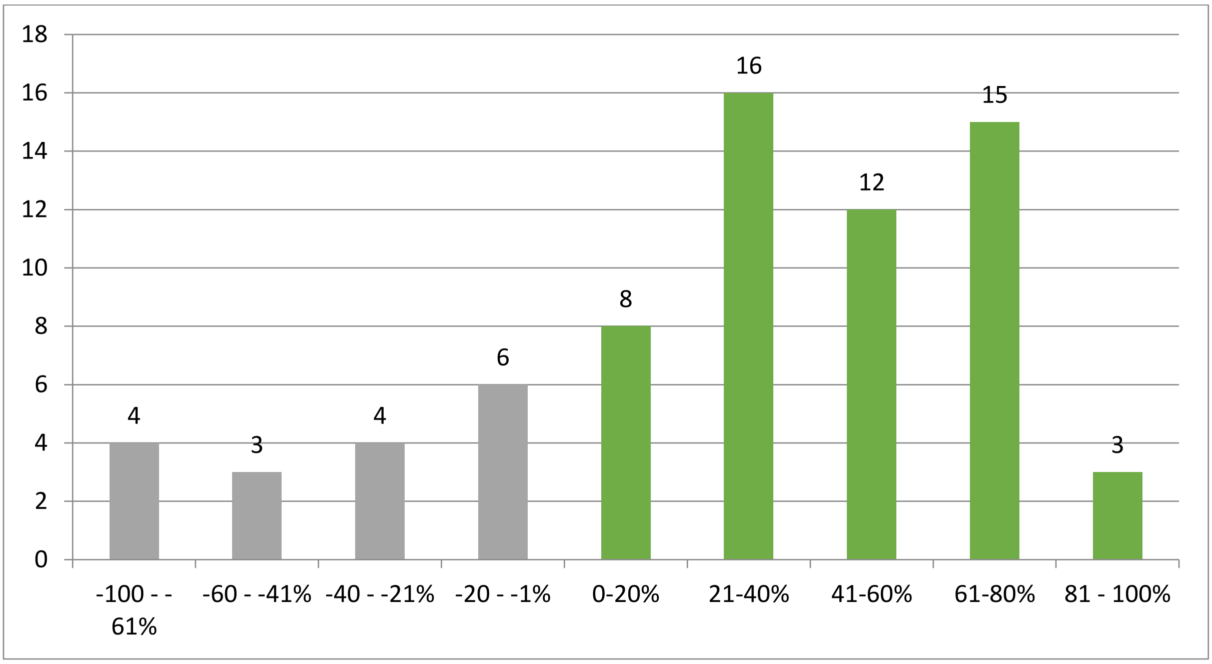


Figure 20: Difference between evaluation of ex ante and ex post CO_2 emission savings.
Source: (Valentová, et al., 2018).

The savings at multi-family buildings seem more stable than in single-family buildings. In the sample, there is clearly higher share of multi-family buildings, for which the ex post CO_2 savings were higher than the ex ante savings (38 % for multi-family buildings compared to 17 % for single-family buildings). The reasons for this are mainly the more compact proportions and stable energy consumption in multi-family buildings; higher discrepancy between the total floor area and actual heated floor area in single-family buildings compared to multi-family buildings, and the fact that the indoor temperatures in individual apartments in the multi-family buildings will in total converge towards an average temperature, approaching the normalized values. All these factors lead to the fact that the normalized calculations used in ex ante evaluations may better reflect the real use of the multi-family buildings.

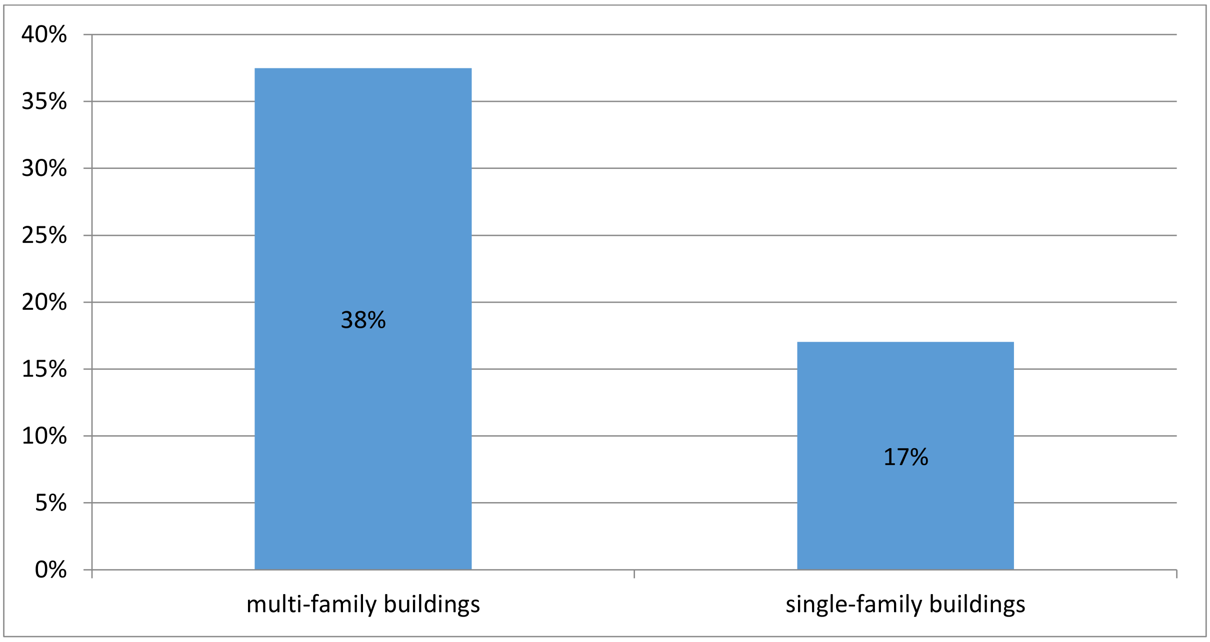


Figure 21: Share of buildings with higher ex post than ex ante CO_2 savings.
Source: (Valentová, et al., 2018).

The highest CO_2 emission savings have been attained through installation of biomass boilers (with feeders or accumulator tanks). Heat pumps were found to be suitable in places where natural gas or biomass is unavailable. Solar-thermal systems have lower impact in single-family houses as they influence mainly hot water preparation. Installations of solar-thermal systems at multi-family buildings seemed more effective.

6.9 Factors influencing the ex post evaluation

The inspections revealed that the reasons, why differences in ex ante and ex post results occurred, can be basically categorized into two main areas: methodical factors and behavioral factors. The two groups are discussed in detail in the following sections.

6.9.1 Methodical factors

Firstly, the method of calculation of energy performance of buildings for the ex ante energy and CO_2 savings in the Czech Republic is given by the Decree 78/2013 Coll. on Energy Performance of Buildings. It is based on standardized use of buildings, disregarding (due to methodical constraints) the differences in the usage by individual end-users. The inspections therefore revealed that the standardized values of energy consumption tended to differ from the real consumption (before the implementation of the measures), resulting in discrepancies between the ex ante and ex post evaluations. Relatedly, temperature differences in different years are not taken into account in the ex post calculations. This also may have caused divergences between the ex ante and ex post calculations. In case of larger projects, such as multi-family dwellings, such differences could be mitigated if real consumption was taken as the background for savings calculations, for instance an average consumption in the last three years, adapted to the long-term climatic average. In case of the Czech Republic, such procedure would be in line with the Decree on energy audits.

Furthermore, in some cases, the interviews with the applicants during inspections revealed that wood firing in a fireplace was used to increase thermal comfort in the buildings before implementation of the energy efficiency measures. However, such consumption could not be included in the ex ante calculation for the purposes of the project application. This in turn may have skewed the results of the ex post inspections.

Similarly, the inspections revealed that in some cases, the heat source was incorrectly categorized in the application, which meant that a different (higher) emission factor was used in the project calculation, artificially increasing the expected CO_2 emission savings of the project.

In one case, the applicant built an extension to the house, while insulating the house, and almost doubled the floor area of the building. Real consumption of the house therefore almost doubled after implementation of the measures.

6.9.2 Behavioral factors

The inspections showed that large part of the differences in ex ante and ex post values in the projects can be attributed to behavioral aspects of the home-owners. Firstly, the applicants asserted they changed partly the way they use their homes after implementation of the measures with different impacts on energy consumption. For instance, thanks to insulation, one applicant claimed they started heating up the cellar of the house, which was not previously heated. Another applicant said they only rarely used the newly insulated parts of the house. Both factors resulting in lower energy and CO_2 emission savings than expected in the project documentation.

Conversely, one applicant stated she just ended her parental leave in the same time that the energy efficiency measures were implemented. This resulted in higher real energy savings than expected in project documentation, as before implementation of the measures, the house was heated the whole day, whereas after implementation of the measures (coinciding with the end of parental leave), the house is now heated only in the morning and in the late afternoon and evening.

In one case, the occupancy of the building changed throughout the course of implementation of the measures, increasing from one to four, therefore increasing the real ex post energy consumption and lowering the resulting energy and CO_2 emission savings compared to the calculated savings in project documentation. Conversely, in one multi-apartments building, the actual occupancy was lower than in the projections. That also makes the ex ante and ex post data incomparable.

In several cases, the applicants reported they used wood firing in a fireplace to help heating up their space. In some cases, the heating in fireplace was reduced after implementation of the energy efficiency measures (specifically, insulation, change of the main heat source). However, such heat consumption is hard to be precisely evaluated and incorporated in the calculations. Therefore, it skews the real energy and CO_2 emission savings.

From the data, it cannot be directly said what is the relationship between the factors above and the resulting difference in ex ante and ex post savings, often, it is a combination of the factors. In other words, the size of the difference, including the extreme values (as presented in Figure 20) seems to be rather case specific.

6.9.3 Qualitative aspects of the implemented measures

Apart from quantitative evaluation of energy and CO_2 emission savings, the inspections also allowed for qualitative assessment of the measures and their implementation, as well as subsidy administration. One of the main goals of the inspections was to assess the overall quality of the implementation of the measures. The inspections found that there were no visible deficiencies in the implementation at none of the inspected projects. One of the reasons for this might be that the subsidized measures could only be carried out by suppliers certified in the Green Savings Programme. Relatedly, with a few exceptions, the applicants expressed overall satisfaction with the implementation of the measures – both with the certified suppliers and with the fact they could carry out the energy efficiency and RES measures.

The applicants that have decided to build their houses in low-energy standards almost unanimously reported that they were happy with the construction companies and the realization of the house. In two cases out of 14 the applicants stated they were unhappy with the construction company (and construction supervisor) and either did most of the work themselves, or hired a foreign construction company. It was caused mainly by higher complexity of the projects. It means that the more complex the project is, the lower the number of construction companies that are able to finalize the project in a sufficient quality. It brings new changes to the nearly zero energy buildings and deep energy renovations. There are already construction companies focused on high standard housing in place, however their share in the market is still low.

The main benefit of the measures mentioned by the applicants were lower costs for electricity and heating and increased thermal comfort after implementation of the measures. The applicants reported significantly lower energy bills and in some cases even the fact that in their apartments, they did not even need to heat most of the rooms in winter. The applicants further enjoyed the increased usage comfort, especially when exchanging the old coal boilers for new, automated biomass boilers, which do not need to be filled for several days.

Several applicants complained that after insulation of the buildings, they detected mold in the buildings. This is caused by improper use of the newly insulated houses, especially lack of regular ventilation of the space. The users may have not been correctly instructed by the suppliers in this sense.

The applicants were asked, whether they would implement the energy efficiency measures even without the subsidy. From the 13 replies, six would do the measures even without subsidy (insulation, low-energy house, solar thermal systems and biomass boiler), in five cases, the applicants said that without subsidy, they would carry out only part of the measures (leaving out mainly solar-thermal systems) or implemented it differently (thinner insulation of a building, natural gas instead of heat pump). Two respondents would not implement the measures at all without a subsidy (both for solar-thermal systems). Even though the sample of respondents is rather small in this case, it shows that the programme rightly supports either the "new" technologies or more complex solutions, such as solar thermal systems, combinations of measures, and higher quality of the measures (thicker insulation).

In several cases, the applicants mentioned the principal-agent problem hindering implementation of energy efficiency measures in their buildings. One multi-apartment building owner asserted he will not benefit directly from the energy efficiency measures. However, he added that he would implement the measures anyways, as he expects they will increase the market value of the building and of the apartments.

Slightly different view is the one of the multi-apartment buildings, where each apartment is owned by the user and altogether the multi-apartment building is managed by the homeowners associations and condominiums. In such case, the body authorized to implement the measures – the elected committee of the building complained it was rather difficult to persuade all the owners who need to give their consent to carry out the project. It seemed that most owners were unable to foresee the benefits of the measures, including both lower energy bills, increased comfort and higher market price of their property. One applicant was so disappointed with the whole process, he claimed that they would consider rather carefully if they were to undergo the whole process again. On the other hand, another building owner asserted, that once implemented, the project served as an inspiration for surrounding houses that followed the example and realized similar measures, too.

7 Case study on Cost optimum of energy efficiency measures

This case study is a result of the activity starting in 2012 and completed in 2016 as a result of the national Cost Optimum calculation. The study introduced in the thesis is condensed paper published in Energy Policy journal as (Karásek, et al., 2018).

7.1 Introduction

It may seem that more substantial energy efficiency measures lead to more energy saved, but this viewpoint takes into account only final energy consumption. Therefore, it is far more important to choose measures that result in a building whose comfort has been improved and which is independent of fuel consumption, as well as to provide measures ensuring 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 based on tenders submitted. In the case of projects at the national or EU level, decisions are made based on insufficient and incomplete databases. In order to make the right decision, it is necessary to create a new tool to visualise data regarding the cost amount and payback period, adding data into statistical tools, or broadening the range of tools focusing on energy efficiency measures as well as on mapping of a building's data (ENTRANZE, 2012), (TABULA, 2016).

The Member States have undertaken to meet the requirements for the calculation of the cost-optimal level of minimum energy performance requirements by using a comparative methodology framework elaborated in accordance 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 (Directive 2010/31/EU, 2010), (BPIE, 2013).

The Member States have reported 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 will 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 and the second one in 2016 (ECOFYS, 2015), (European Commission , 2016).

7.2 Goals of the study

The main goal of this study is to present selected results of the unique national cost optimum calculation model, including the methodology applied. The text covers both the EU methodological level and specific implementation at the national level. To introduce the study results, family houses and apartment buildings were selected in order to cover the highest share of the national building stock.

The second goal of this work is to document the cost development of energy efficiency measures. Costs calculation of energy efficiency measures is based on the methodology for calculating energy performance referred to in Decree 78/2013 Coll., on energy performance of buildings. The Decree also sets the cost-optimal level of requirements for energy performance of buildings derived from the calculation of their technical and economic parameters.

In order to meet the requirements of the Decree, it is necessary to achieve lower values of energy performance indicators than presented by the values for so-called reference building. This can also be understood as the low level of the necessary investments and as determination of the minimum price of energy efficiency measures. The prices of building materials used during a renovation as a measure for improving the energy performance of a building were obtained by means of demand and analysis of the market for each locality in the country.

The total costs of energy efficiency measures for individual buildings may differ, as costs calculation is determined by myriad factors which can substantially affect the result. The resulting costs depend on how the calculation is carried out and on the documents used. The calculation is thus affected by the building location, because the availability of building materials and the capacity of construction companies may vary.

Another factor which can influence the costs of energy efficiency measures is higher energy prices, which puts pressure on users. At the same time, the Czech Republic is trying to achieve predetermined energy savings. The market demand keeps on increasing, which creates pressure to increase the price of energy efficiency measures. For the sake of documentation, heating demands with reference buildings have been established and resulting costs for individual localities have been summarised.

7.3 International experience with life-cycle costing

Buildings as results of construction projects are characterised by long lifespan and high costs. This is why all decisions connected with construction projects have long-term and significant impact (Ryghaug & Sørensen, 2009). Construction project investors often focused simply on the acquisition costs when deciding on the building design, equipment and energy systems, frequently neglecting future operation or maintenance costs (Jakob, 2006). Due to the lack of a holistic view of the true costs of a building, a cost-inefficient solution might be selected. Lifecycle costs (LCC) in general consist of an initial investment (usually construction costs) and the follow-on costs (ordinary payments, i.e. energy, utilities, cleaning and maintenance, irregular costs for renewal or replacement), while some lifecycle costing methods also include the costs of demolition (Kovacic & Zoller, 2015). Lifecycle costing is often recommended for determining cost-optimal solutions for product design and is becoming more frequently used in the design phase of buildings generally.

Lifecycle costing is a method that helps estimate the total cost of ownership. The technique can help make decisions within building investment projects (Flanagan, et al., 1989). Lifecycle costing is particularly useful for estimating total costs in the early stage of a project (Bogenstätter, 2000). The lifecycle costing process usually includes the following steps:

- Planning of the lifecycle costing analysis (e.g. definition of objectives);
- Selection and development of the lifecycle costing model (e.g. cost breakdown structure, identifying data sources and contingencies);
- Application of the lifecycle costing model;
- Documentation and review of lifecycle costing results.
- Extensive research has been performed and a report has been published focusing on lifecycle costing (Davis Langdon, 2007). One well-described LCC method is so-called cost-optimal calculations.

7.4 Approaches to cost-optimal calculations

New methods are being developed to help decision-makers in the planning process. A supporting method for selecting cost-optimal energy retrofit policies for residential buildings at the urban scale created by Delmastro allows the development of building stock to be simulated and analyzed from the perspectives of energy, economy and society over the long term. One of the goals of the study is to identify a cost-optimal combination of successful renovation packages. The method is verified by urban calibration coefficients depending on the urban energy balance (Delmastro, et al., 2016).

The emphasis on the correctness of the input data in creating cost-optimal construction design and its impact on the results is also shown in the text of cost-optimal nZEBs in future climate scenarios. Due to ongoing global changes, it is necessary to study and guarantee the resilience of the design of the nZEB to changes in the boundary conditions in which the cost-optimal calculation is carried out (Ferrara &

Fabrizio, 2017). A similar effect of weather and climate change on the economic viability of energy-saving measures also has an influence on the costs.

Several studies on cost-optimum calculation have been introduced. The cost-optimal urban energy systems planning in the context of national energy policies: A case study for the city of Basel (Yazdanie, et al., 2017), Energy retrofit alternatives and cost-optimal analysis for large public housing stocks (Guardigli, et al., 2018). Another study to which it refers is a study that focuses on research into cost-optimal options and efficiency measures in new buildings depending on the climate. The data presented in this text relates to the modelling of building energy consumption, renewable energy, potential energy savings, and costs (D'Agostino & Parker, 2018).

Most studies focus on the cost optimum in terms of energy savings, but do not emphasize cost input data and their impact on the return on investment. Although the various costs of purchasing energy-saving measures do not have a direct impact on the amount of energy savings achieved, they are crucial when determining the project's feasibility. As national cost optimum calculations have not been introduced as a scientific text yet, an EU comparison of the approaches applied is not possible.

EU Regulation No. 244/2012 issued in 2012 complements EU Directive 2010/31/EU of the European Parliament and of the Council on energy performance of buildings. (EP, 2010) The regulation establishes a comparative and methodology framework enabling the calculation of cost-optimal levels of minimum energy performance requirements for buildings and their elements. EU Regulation No. 244/2012 is accompanied by general guidelines which are not legally binding. However, the guidelines provide EU Member States with relevant additional information and reflect principles adopted for the calculation of costs arising from the Regulation. As such, these general guidelines should facilitate the application of the Regulation and it is the amended version of the Regulation which is legally binding and which is directly applicable in the Member States. It is important to select the right evaluation method.

The related legislation has not been changed since 2013, when the last national report on the calculation of cost-optimal levels was submitted (Trianni, et al., 2014). The described changes refer to the year 2012.

Between 2013 and 2015, the European Commission tasked Ecofys with elaborating a document evaluating all national reports on the calculation of cost-optimal levels submitted (ECOFYS, 2015). The document involves a comparison of various Member States and their approaches towards the cost optimum calculation. Such data is comparable e.g. via database processing software (Hromada, 2016). The best examples (e.g. Slovakia and Denmark) were chosen to demonstrate the comparison. The document also offers proposals for adjustments and guidelines supplementing EU Regulation No. 244/2012 (Fleiter, et al., 2012)

7.5 Methodology framework to identify cost-optimal levels of energy performance requirements for buildings

The comparative methodology framework is to enable Member States to determine the energy performance of buildings and building elements. The framework is accompanied by guidelines outlining how to apply the framework in the calculation of cost-optimal performance levels. The framework should also allow to be taken into account, where applicable, for consumption patterns, outdoor climate conditions, investment costs, building category, maintenance and operating costs (including energy costs and savings), earnings from energy produced, and disposal costs. The framework is based on relevant European standards relating to this directive (BPIE, 2010).

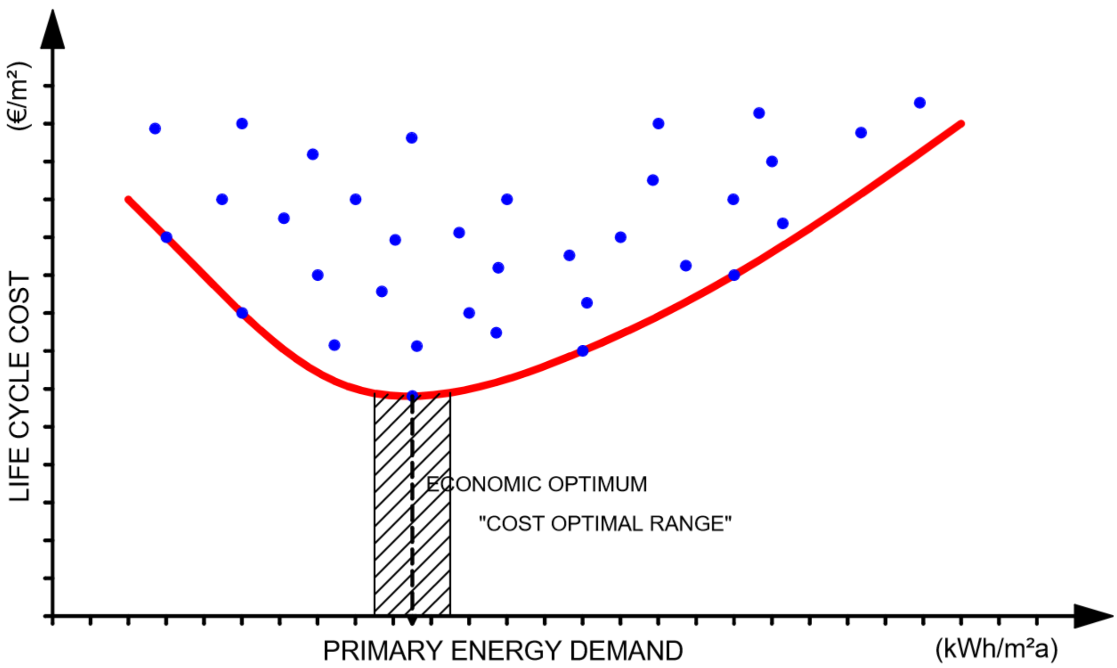


Figure 22: A cost optimum scheme.

Source: (Regulation 244/2012, 2012).

7.6 National calculation of cost optimum

Calculation of total costs

The total costs calculation for each reference building considers the initial investment, the sum of annual costs for each year and the final value (i.e. residual value of elements and services with lifespan exceeding the end of the assessment period), all with reference to the starting year. The calculation of total costs results in the net present value of costs incurred during a defined calculation period.

As opposed to the annuity method, the global cost method allows the use of a uniform calculation period (with long-lasting equipment taken into account via its residual value) and can make use of lifecycle costing (LCC), which is based on the calculation of net present value as well. The term "global costs" is taken from the ČSN EN 15459, 2010 standard and corresponds to what is generally called "lifecycle cost analysis".

It should be noted that the global cost methodology as prescribed in the Regulation does not include costs other than those related to energy (e.g. water costs), as it follows the scope of EPBD II (Directive 2010/31/EU, 2010). The global cost concept is not fully in compliance with the entire Lifecycle Assessment (LCA), which would take into account all environmental impacts throughout the lifecycle, including embodied energy (ČSN ISO 15686-5, 2014), (ČSN EN ISO 13790, 2009). Both norms have been Update in 2018.

7.6.1 The cost-optimality concept

In accordance with the EPBD II Directive, the Member States shall determine cost-optimal levels of minimum energy performance requirements. General cost-optimal levels at the national level may not be cost-optimal for every single building or for a combination chosen by the investor. However, the goal of the study is to determine suitable reference buildings and to carry out a combination of measures ensuring that the identified cost-optimised requirements (subsequently applied in legislation) result in a level that is satisfactory for both new and existing buildings.

Besides various and possibly numerous perspectives and investment expectations, the question of the costs and benefits must be taken into account. The methodology arising from (Regulation 244/2012, 2012) defines two economic perspectives considering the calculation of cost-optimal levels. Furthermore, the methodology instructs the Member States to carry out:

- A financial calculation (investor's point of view); and
- A macroeconomic calculation (taking into account society as a whole).

7.6.2 Unit rate calculation

Unit rates are usually a sum of rates for labour, plant, materials and subcontractors. The way in which unit rates are built up differs from company to company and among trades. The resources required to construct a building (i.e. labour, materials, plant and equipment, as well as site-based overheads or preliminary costs) should be fully included and priced. The estimate of the unit rate is covered by the aggregate anticipated costs of all these items. However, the estimate established by this method includes only direct construction costs. Contractors' overheads and required profit are additional items.

The unit rate must include:

- The direct labour element for that item of work (all-in hourly rates);
- The costs of the materials needed (with appropriate allowance for shrinkage, bulking and wastage);
- The costs of any items of plant or equipment which are used solely for that item and are not priced elsewhere, e.g. in preliminaries;
- The work carried out by subcontractors, costs associated with preliminaries and site overheads.

Table 6: Form of unit rate calculation

Cost	Calculation
Materials (purchase costs, order cost, storage costs)	M
Labour (all-in rate, e.g. incl. allowance, insurance, holiday)	L
Plant and equipment	PE
Subcontractors	SUB
Overheads (site), preliminary	OS
Direct costs	DC = M+L+PE+SUB+OS
Overheads (head office)	OH
Profit (loss)	P
Unit rate	UR = DC+OH+P

Source: (Karásek, et al., 2018).

Costs and price calculation of measures for the cost-optimal level is based on a standard costing scheme adjusted and adapted to the needs of the study (Heralova, 2014).

7.7 National definition of reference building

A reference building is a real evaluated building (having the same properties, i.e. type, geometric form and dimensions, including glazed areas and elements, orientation, shading from nearby buildings or trees, interior structure, type of use, and climatic factors considered), but has reference values of the building properties, its structure and technical service systems of the buildings (Decree 78/2013: Vyhláška o energetické náročnosti budov (Decree on Energy Performance of Buildings), 2013).

A comparative methodology framework requires that the Member States (Directive 2010/31/EU, 2010):

- Define reference buildings characterised by their functionality and geographic location, including indoor and outdoor climatic conditions;
- Define energy efficiency measures to be assessed for reference buildings;
- assess the final and primary energy need of reference buildings and reference buildings with defined energy efficiency measures applied;
- Calculate the costs of energy efficiency measures during the expected economic lifecycle by applying the principles of the comparative methodology framework.

By calculating the costs of energy efficiency measures during the expected economic lifecycle, the Member States assess the cost effectiveness of various levels of minimum energy performance requirements. This shall also enable the cost-optimal levels of energy performance requirements to be defined.

7.8 Changes of input parameters for the year 2016

The changes of input parameters concern:

The VAT rate – it was 20% in 2012, while in 2016 it is 21%. In addition, a 15% rate is currently used in the Czech Republic in the area of social housing – a rate used for specific cases of FH and AB.

Fuel and energy prices – heating and natural gas prices in 2012 and 2016 were almost identical, but electricity prices have plummeted. 1 GJ of electrical energy costs about CZK 1,300 in 2012 including VAT. In 2016, the average price for electricity was CZK 1,030 CZK/GJ including VAT. Tariffs for electric heaters and heat pumps have also been reduced. In contrast, prices of lignite and biomass have increased.

Climate data – climate data for the calculation of energy performance are set out in TNI 73 0331. The values of monthly solar radiation doses H in kWh/ (m^2. month) in 2016 are the same as they were in 2012.

Building structure – it is very difficult to determine price and parameter changes regarding the building structure because of technological and price development (depending on supply and demand). Specifically selected prices of building material and work are mentioned in this text. For example, the total price of measures for external walls is significantly lower than in 2012, which is mainly due to the price of the building material intended for end consumers. The total price of measures has decreased by more than 30%.

Building services – no significant changes of prices or input parameters have been recorded since 2012. The only area which has witnessed any remarkable decrease is energy efficiency in lighting – the decrease of specific electricity consumption is caused by the spread of LED technology. Due to the individual character of Building services supply, only estimates were used in the calculation model.

The observed current values of prices may be used to calculate the return on investment to the energy saving measures, and to gain better insights into the economic value of measures that can be compared to other EU countries (Chegut, et al., 2016).

7.9 Pricing documents updates

As a consequence of continuing price development of building elements, materials and construction work, a detailed survey of the construction material market was carried out. The survey aimed at obtaining current prices needed for the cost calculation of various energy efficiency measures.

7.9.1 Approach to the price data collection of building materials

Fourteen producers and wholesalers of building materials were contacted for this study, as were various construction companies and retailers selling building materials.

The current market offers a significant number of materials as well as producers and sellers. The ultimate customer, be it an individual or legal entity, can buy building materials from wholesalers like Saint-Gobain (Isover, Weber and others), or e.g. Rockwool, Heluz, Wienerberger, Baumit, etc. However, building materials can also be bought in retail chains like DEK or from retailers selling building materials in towns. In total 12 large companies have been contacted. The most important part was related to the thermal insulation producers. Moreover, four retail markets of construction materials have been contacted and seven construction material sellers have been personally approached. The labour cost estimate was based on particular offers of the construction companies.

Prices in shops may vary greatly and can be influenced by many factors. It is believed (often wrongly) that buying building materials via the internet is cheaper. However, catalogue prices found on websites or in printed catalogues often give only rough prices and the final price is determined by the sales quantity, delivery distance, or by the region or district. Retail prices are also influenced by various factors. Low prices cannot be expected from small retail outlets, as they are not able to gain low prices for quantity or other benefits from suppliers. A number of suppliers selling the same type of material compete with each other and offer special prices and sales. Building products sellers with significant sales gain rebates for ordering large quantities. Locality is another important factor affecting the price of building materials, since the manner and extent of use is vastly different for building materials in various regions, which affects the price, too. From 20 contacted producers, 16 answered the questions. About 70% answered all questions, the rest answered just partially.

For instance, the percentage of clay ceramic bricks and aerated concrete bricks used in South Bohemia varies even within particular districts. The district of Český Krumlov uses clay ceramic bricks significantly more often than aerated concrete bricks, while in the district of České Budějovice the difference is quite negligible. This fact has an effect on the final price: the price of clay ceramic bricks is higher in the České Budějovice district, while aerated concrete bricks are cheaper than in the Český Krumlov district. Prices used in the study were gained from pricelists of major manufacturers and suppliers as well as retailers.

The facts stated above are easier to specify for manufacturers and sellers of building materials than, for instance, for manufacturers and sellers of windows. Although some prices of windows and doors are stated, it is always necessary to create demand for a specific product. The prices of various window sizes, frame types and glazing quality differ in shops. For the purpose of this study, window prices were gained from manufacturers and sellers of doors and windows. Most of the companies were contacted personally, by phone or by email. Those are not official documents to be cited. All websites referred to are included among the sources.

7.9.2 Construction work pricing

Costing for various types of construction work is dependent on many aspects. First, there is the costs difference between new building and renovations. The price of the latter depends largely on the condition of the renovated building. Another aspect influencing the costs of construction work is the size of the material (window size, thickness of thermal insulation).

For the purpose of this study, construction companies were contacted at the level of site managers and quantity surveyors. The approaches of individual companies varied. Invariably, construction work costing involves several actions or steps, which various companies may handle differently. First, it is necessary to define all these actions related to construction work. As soon as these actions are defined, it is possible to demand costs. Defining costs of construction work is a difficult process and accurate documentation and division into individual steps is necessary.

In the case of thermal insulation of the building envelope, roof and floor structure, it was very difficult to define what these involve and what they do not. The prices of doors and windows were set by the manufacturers and suppliers themselves based on material demands.

7.9.3 Pricing updates of material and work

Prior to the actual gathering of information on material and work costs, it was necessary to decide which actions fall into the particular type of construction work and which materials should be used. The line between what is involved in thermal insulation and what is not is very thin. In the case of Operational Programme Environment aid schemes, thermal insulation is understood as involving only direct eligible costs relating to implementation of the measures per se, i.e. material and work resulting in improvement of the insulation properties of the building envelope. The lines defining the scope of thermal insulation may slightly differ in this study.

As can be seen from the above information, the costs of material and work involves only basic material and work closely related to improvement of the thermal-technical characteristics of a building. The renovation measure includes works starting with demolition and finishing with the cleaning of the completed construction. The selection of measures is based on the experience with energy auditing.

The costs of individual measures were determined based on lines defining the price of material and material prices obtained. Two prices were set for various thicknesses of insulation material (a price according to the pricelist and the sales price). Prices of materials which cannot be specified in square metres are set according to manufacturers' methodology in metres or pieces (e.g. six pieces of wall plugs per square metre) or according to percentage estimation with regard to the area of the building (corners covered with textile, apu beads, etc.).

7.9.4 Prices of materials used for thermal insulation of a building envelope

Table 7 lists basic materials which can be used for insulation of a building envelope. The best-selling materials were used for the calculation and the sales quantity was gained from sellers of building materials. Along with the price, thermal resistance of the structure installed was calculated. For thermal insulation, the considered value of thermal conductivity is λu= 0.039 W/(m.K).

For polystyrene, the considered value of thermal conductivity is λu= 0.038 W/(m.K) and this value has been increased by 2% as a consequence of water absorption. With mineral fibre the considered value of thermal conductivity is λu= 0.036 W/(m.K), but because of water absorption the value has been increased by 8%.

Table 7: Prices of material used for thermal insulation of a building envelope depending on insulator thickness per square metre.

Envelope (total)	Insulator thickness (mm)	List price in € (incl. VAT)	Sales price of building materials in € (incl. VAT)	Thermal resistance of a filled structure (m^2K/W)
Polystyrene	80	20,92	10,39	2,13
	100	30,43	11,12	2,64
	140	27,36	12,66	3,67
	160	29,61	13,51	4,18
	200	34,26	15,58	5,21
Mineral fibre (MF)	80	27,05	15,18	2,13
	100	30,68	17,08	2,64
	140	38,08	21,03	3,67
	160	41,86	23,06	4,18
	200	49,59	27,51	5,21

Source: (Karásek, et al., 2018).

The above table indicates that catalogue prices are nearly twice as high as sales prices. Furthermore, the figures in the table show that mineral fibre is far more expensive than polystyrene with similar thermal properties. The higher price is due to the higher insulation price as well as the price of additional materials (more quality glue for fixing and palette knife work, metal wall plugs). At the same time, no other technical properties are shown in the table accounting for price differences between polystyrene and mineral fibre.

7.9.5 Prices of materials used for insulation of a roof structure

The following table shows basic materials commonly used for insulation of a roof structure. Table 8 shows prices including VAT. The prices are based on a study of offers of selected suppliers. The table compares the list price and the real selling price (included offered discount).

Table 8: Prices of material used for insulation of a roof envelope per square metre.

Material		Price for m^2 (or for m)	
Category	Subcategory (mm)	List price in €	Price of building material in €
Mineral fibre (MF) Isover	50	3.23	3.19
	100	6.45	6.37
	140	9.05	8.96
	160	10.31	10.22
	180	11.61	11.48
	200	12.91	12.74
MF Isover (rolls)	80	4.57	3.41
	100	5.74	4.22
	120	6.90	5.11

	140	8.02	5.93
	160	9.19	6.81
	180	10.31	7.63
	200	11.47	8.44
	220	12.64	9.33
Vapour control layer		1.88	0.81
Adhesive tape		2.87	0.74
Additional waterproofing		2.20	0.89
Fixings		1.17	3.19

Source: (Karásek, et al., 2018).

The volume discount was identified from sellers of building materials. The prices of materials were calculated together with the thermal resistance of the structure installed. With thermal insulation, the value considered for thermal conductivity is λu= 0.039 W/(m.K).

7.9.6 Prices of materials used for insulation of a floor structure

Another study has been carried out to present results for floor constructions. The following table shows common materials used for floor insulation. Catalogue prices are compared with the prices that were identified in offers provided by suppliers.

Table 9: Prices of materials used for insulation of a floor structure.

Material		Price per m2 (or for m)	
Category	Subcategory (mm)	List price in €	Price of building material in €
Polystyrene (floor)	40	6.90	3.26
	50	8.63	4.00
	80	13.80	6.44
	100	17.26	8.00
	120	20.70	9.63
Fixings (glue)	80	2.48	1.56
Concrete layer of the floor (100 mm)	100	7.78	7.78

Source: (Karásek, et al., 2018).

The price of material was calculated together with the thermal resistance of the structure installed. The above table indicates the prices of building materials. It can be seen that the sales price is lower than the price listed in the catalogue. The difference between the list price (catalogue price) and the bid price increases with increasing insulation thickness. For insulation with thickness of 120 mm, the difference is almost 60% of the list price.

7.9.7 Prices of materials used for installation of doors and windows

The following table shows essential materials which can be used for the installation of doors and windows. The table shows only basic materials. Three types of material and two types of glazing were requested. In all cases, the frame type was chosen with regard to the medium (best-selling) quality. As a matter of course, higher quality frames are designed for higher quality glazing and vice versa.

Window frames requested:

- Wooden;
- Aluminium;
- Plastic.

Glazing requested:

- U= 1.2-1.1 W/(m^{2}K);
- U= 0.85-0.75 W/(m^{2}K).

Plastic window sills were requested for plastic and aluminium windows and wooden window sills were requested for wooden windows. The following table introduces windows whose price neither exceeds average prices. Fluctuation in the price could be caused by inaccurate demand or quality of the material notably differing (for better or for worse) from other requirements.

Table 10: Prices of materials used for installation of doors and windows

Material		Package			
Category	Subcategory	Price	Size (mm)	Price for m2 (or for m)	Total price for m^2 in €
Plastic windows RI OKNA U=1,1	Material - window	150,6	1500x1500	66,9	3,4
	Window sill int	11,1	1500	7,4	
	Window sill Ext	9,25	1500	6,2	
Aluminium windows RI OKNA U=0,75	Material -window	585,1	1500x1500	260,1	11,7
	Window sill int	11,1	1500	7,4	
	Window sill Ext	9,25	1500	6,2	
Plastic Oknotherm U=1,2	Material – window	134	1500x1500	59,6	3,5
	Window sill int	8,64	1500	5,8	
	Window sill Ext	16,3	1500	10,9	
	Accessories	5,1	-	5,1	
Plastic Oknotherm U=0,73	Material - window	206,3	1500x1500	91,7	8,6
	Window sill int	8,6	1500	5,8	
	Window sill Ext	16,3	1500	10,9	
	Accessories	5,1	-	3,4	
	Material - window	326,9	1500x1500	145,3	

Wood - Oknotherm U=1,2	Window sill int	37,0	1500	24,7	7,8
	Window sill Ext	17,0	1500	11,4	
	Accessories	4,3	-	2,9	
Wood Oknotherm U=0,82	Material – window	804,4	1500x1500	357,5	20,7
	Window sill int	37,0	1500	24,7	
	Window sill Ext	17,0	1500	11,4	
	Accessories	4,3	-	2,9	

Source: (Karásek, et al., 2018).

The resulting prices per square metre differ slightly due to the range of products of various manufacturers. Accordingly, the final calculations are accompanied by the window prices in the Oknotherm company offer.

7.9.8 Work pricing

Based on the boundaries set by the Operational Programme Environment and based on the prices obtained for all types of work (individual and total), the prices of individual measures have been established. Two different prices were established for various thicknesses of insulating material (in case a construction company considered higher prices for wider structures).

Work pricing for building envelope insulation

Table 11: Work pricing for a building envelope insulation depending on insulator thickness per square metre.

Envelope (total)	Insulator thickness (mm)	Price (incl. VAT)	Price – reconstruction (incl. VAT) in €
Polystyrene	80	17.78	22.22
	100	18.52	22.96
	140	18.89	23.33
	160	19.26	23.70
	200	19.63	24.07
Mineral fibre (MF)	80	19.63	24.07
	100	20.37	24.81
	140	20.74	25.19
	160	21.11	25.56
	200	21.48	25.93

Source: (Karásek, et al., 2018).

The previous Table 11 shows the average price for insulation of the building envelope. There are values shown for two selected materials and for various insulation thicknesses. The table displays various values at the costs of insulation for new construction and reconstruction. Prices include VAT.

Work pricing for insulation of a roof structure

Table 12: Work pricing for roof structure insulation depending on insulator thickness per square metre

Envelope (total)	Insulator thickness (mm)	List price (incl. VAT)
MF Isover (boards)	50	6.67
	100	7.41
	140	8.15
	160	8.52
	180	8.89
	200	9.26
MW Isover (roll)	80	7.04
	100	7.41
	120	7.78
	140	8.15
	160	8.52
	180	8.89
	200	9.26
	220	9.63

Source: (Karásek, et al., 2018).

Table 12 shows current prices for roof insulation, divided into two parts; one shows prices for mineral wool in the form of slabs and the other in the form of a roll. In both cases, the prices are divided according to the thickness of insulation.

Work pricing for insulation of a floor structure

Table 13: Work pricing for insulation of a floor structure depending on the insulator thickness per square metre.

Envelope (total)	Insulator thickness (mm)	Price in € (incl. VAT)
Polystyrene (floor)	40	6.07
	50	6.07
	80	6.07
	100	7.41
	120	7.41

Source: (Karásek, et al., 2018).

Comment:

Table 13 shows polystyrene-based floor insulation of various thicknesses. Again, the table is divided according to the thickness of the insulation and the prices include VAT.

Tables 13 – 14 show current prices obtained from a study from suppliers of materials. These prices can be used to calculate the cost optimum more accurately.

7.9.9 Prices of work used for installation of door and window

The following table shows basic prices of work which can be used for the installation of doors and windows. The table lists only basic materials. Windows sized 1500 x 1500 were requested here, as windows sized 1000 x 1000 could lead to price distortion caused by different work pricing (due to different sizes).

Table 14: Work pricing of windows and doors installation

Material		Package	Price for m2 (or for m) in €		Installation price in €
Category	Subcategory	Dimension (mm)	Installation	Disassembly	
Plastic RI U=1.1	Window installation	1500x1500	31.11		100.52
	Window sill int	1500	16.30		
	Window sill Ext	1500			
	Brick work + disassembly	-	40.00	11.11	
Alluminium RI WINDOWS U=0.75	Window installation	1500x1500	48.33		133.47
	Window sill int	1500	27.74		
	Window sill Ext	1500			
	Brick work + disassembly	-	40.00	11.11	
Plastic Ok-notherm U=1.2	Window installation	1500x1500	31.11		97.11
	Window sill int	1500	11.11		
	Window sill Ext	1500			
	Accessories	-			
	Brick work + disassembly	-	42.22	5.93	
Plastic Oknotherm U=0.73	Window installation	1500x1500	31.11		97.11
	Window sill int	1500	11.11		
	Window sill Ext	1500			
	Accessories	-			
	Brick work + disassembly	-	42.22	5.93	
Wood Ok-notherm U=1.2	Window installation	1500x1500	31.11		97.11
	Window sill int	1500	11.11		
	Window sill Ext	1500			
	Accessories	-			
	Brick work + disassembly	-	42.22	5.93	
Wood Ok-notherm U=0.82	Window installation	1500x1500	31.11		97.11
	Window sill int	1500	11.11		
	Window sill Ext	1500			
	Accessories	-			
	Brick work + disassembly	-	42.22	5.93	

Source: (Karásek, et al., 2018)

Multiplication by square metre could cause inaccuracies of the installation price. The total price for the whole window surface is not equal to the multiple of square metres (a 1x1 window and a 1.75x1.5 window is installed for a similar price). If the windows are bigger than 1 square metre, the total price of work (multiplied by surface) would be at least twice as high as it really is. A more accurate calculation could be attained by multiplying the price of work by the number of doors and windows or by using a coefficient that would reduce both the surface and quantity of door and windows. The coefficient would be based on window sizes (in the case of a large number of small windows, the coefficient would be approximately 0.9, while in the case of a smaller number of larger windows, it would be approximately 0.7).

Another difference is between a renovated and new building. Renovation also includes disassembly and masonry finishes, as opposed to a new building, which includes only installation. The price of window installation in a new building is approximately CZK 1,000 cheaper (per window). Disposal of old windows and transportation are not included in the price.

7.10 Results

This work has compared data regarding the costs of energy efficiency measures for various locations. The data have shown that costs depend on the development of demand pertaining to energy efficiency measures and material as well as on the availability of construction companies. Furthermore, data needed for an estimate of price development relating to future energy efficiency measures (depending on development from the time of EPBD II implementation) have been gathered.

Based on the data found, it is possible to demonstrate different values of catalogue and sales prices. Almost all item sheets show catalogue prices higher than those offered by the companies that were addressed. With respect to insulating materials used for roof renovations, the price difference is more than doubled.

The price data which have been identified enable material and work pricing for the year 2016 to be determined. Different types of structures show different results. A comparison of results from 2012 and 2016 proves costs savings in 2016 as regards some measures, e.g. the total costs of measures for external walls have decreased by 30%. Door and window are another example of a significant price drop (by 40% in comparison with 2012).

Pricing depends on the type and thickness of material, but can also be influenced by the sales policy of the company offering the product in question. This results in different prices of the same products (depending on the supplier).

Selected model results based on updated inputs

Preliminary estimates and proposed measures use sheets on values of material and work prices. As has been stated above, these values should be regularly updated to reflect the current state of the market and create a true and fair model.

It is also possible to use values when searching for the optimal level of measures. As soon as the exact value of a level is determined (based on current work and material pricing), it is possible to establish the ideal level of measures which would meet the needs of both the investment expectations and payback period of the investment in particular measures.

The following figure shows the values for material and work pricing used during the calculation of total costs for a building optimisation that has been carried out. The model offers a few variants of the same building with different parameters regarding heating technologies and the heat transmission coefficient of the building envelope which has been achieved.

Table 15: Overview of variants, related to Figure 2.

SYSTEM	VAR A (1-4)	VAR B (1-4)	VAR C (1-4)	VAR D (1-4)	VAR E (1-4)	VAR F (1-4)
Heating	Natural gas	Electric heater	Heat pump	Coal boiler	Biomass boiler	District heating
Hot water preparation	Central	Local	Central	Central	Central	Central
VAR (1-4)	**1**	**2**	**3**	**4**		
Heat transmission coefficient	Required	Recommended	Passive houses (less stringent values)	Passive houses (stringent values)		

Source: (Karásek, et al., 2018).

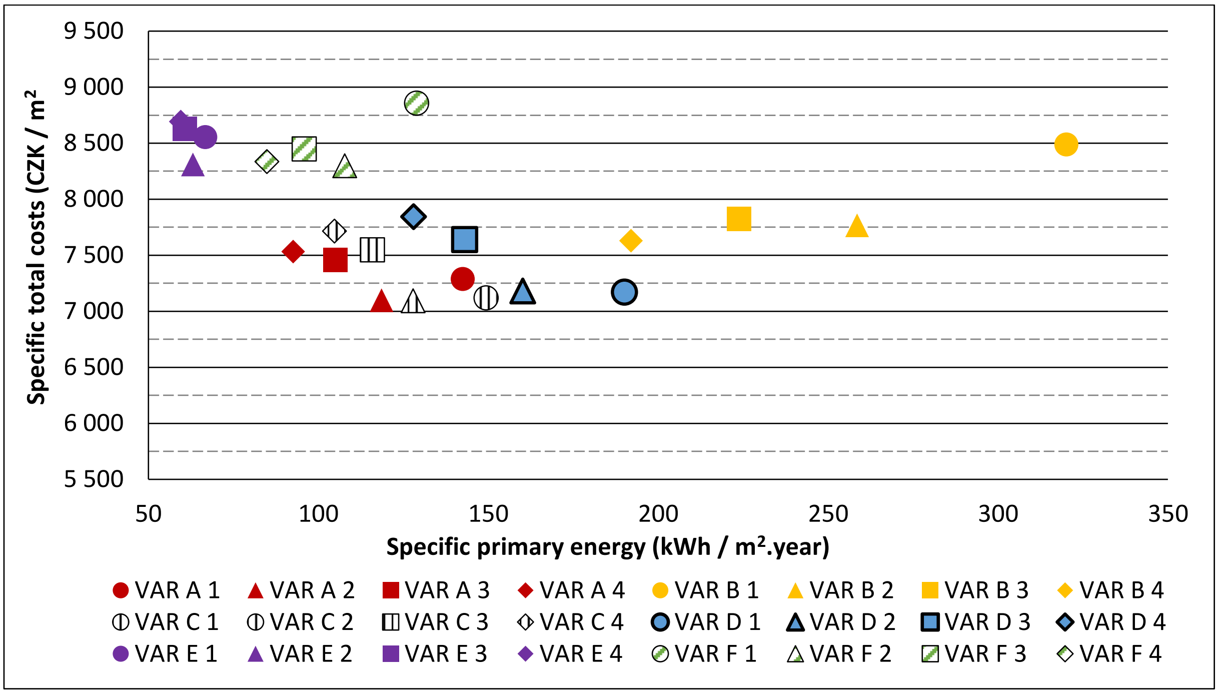


Figure 23: Cost optimization for a family house (natural ventilation)
Source: (Karásek, et al., 2018).

The following table shows the various parameters of the heating system. All variants, however, involve quality energy efficient lighting and natural ventilation, while no solar collectors are considered.

Table 16: Prices of materials used for building envelope insulation.

Material					List price		Price of a building product	
Category	Subcategory	Package	Consump-tion per m²		Price per piece (package)	Price for m² (or for m) in €	Price per piece (pack-age)	Price for m² (or for m) in €
Polystyrene EPS (70) F	Polystyrene 1 cm	1	2	Pc	0.47	0.94	0.16	0.32
	Polystyrene 8 cm	1	2	Pc	3.75	7.49	1.27	2.55
	Polystyrene 10 cm	1	2	Pc	8.39	16.77	1.59	3.19
	Polystyrene 14 cm	1	2	Pc	6.56	13.11	2.22	4.44
	Polystyrene 16 cm	1	2	Pc	7.49	14.99	2.54	5.07
	Polystyrene 20 cm	1	2	Pc	9.37	18.73	3.19	6.37
MF	MW 2 cm	1	2	Pc	1.70	3.41	1.24	2.48
	MW 8 cm	1	2	Pc	6.81	13.62	3.67	7.33
	MW 10 cm	1	2	Pc	8.51	17.03	4.57	9.15
	MW 14 cm	1	2	Pc	11.92	23.84	6.41	12.81
	MW 16 cm	1	2	Pc	13.62	27.24	7.31	14.63
	MW 20 cm	1	2	Pc	17.03	34.06	9.15	18.30

Glue (dual use)	Baumit StarContakt (glu-ing/fixing)	25	3.5	Kg	17.70	2.48	11.11	1.56
	Baumit StarContakt (pal-ette knife)	25	5	Kg	17.74	3.55	11.11	2.22
	Baumit DuoContact (glu-ing/fixing)	25	3.5	Kg	8.63	1.21	5.19	0.73
	Baumit DuoContact (pal-ette knife)	25	5	Kg	8.63	1.73	5.19	1.04
Wall plugs	Facade 80 (dimension 8*115)	1	6	Ks	0.25	1.49	0.15	0.91
	Facade 100 (dimension 8*135)	1	6	Ks	0.28	1.69	0.16	0.98
	Facade 140 (dimension 8*175)	1	6	Ks	0.37	2.20	0.20	1.20
	Facade 160 (dimension 8*195)	1	6	Ks	0.43	2.56	0.23	1.40
	Facade 200 (dimension 8*235)	1	6	Ks	0.57	3.40	0.36	2.13
Penetration (Baumit)	Uni primer	25	0.25	Kg	67.22	0.67	47.41	0.47
Plaster (Bau-mit)	Silicone 1.5	25	2.5	Kg	67.22	6.72	36.48	3.65
	Silicone 2	25	2.9	Kg	67.22	7.80	36.48	4.23
	Silicone 3	25	3.9	Kg	67.22	10.49	36.48	5.69
	Silicate 1.5	25	2.5	Kg	56.22	5.62	34.48	3.45
	Silicate 2	25	2.9	Kg	56.22	6.52	34.48	4.00
	Silicate 3	25	3.9	Kg	56.22	8.77	34.48	5.38
	Acrylic 1.5	25	2.5	Kg	51.31	5.13	32.59	3.26
	Acrylic 2	25	2.9	Kg	51.31	5.95	32.59	3.78
	Acrylic 3	25	3.9	Kg	51.31	8.00	32.59	5.09
Net	Baumit Startex	50	1.1	m	54.67	1.20	35.19	0.77
	Baumit duotex	50	1.1	m	48.47	1.07	31.48	0.69
Additional beads	Edging bead 8 cm	2	1	m	3.26	1.63	2.41	1.20
	Edging bead 10 cm	2	1	m	3.74	1.87	2.81	1.41
	Edging bead 14 cm	2	1	m	5.34	2.67	4.00	2.00
	Edging bead 16 cm	2	1	m	5.85	2.93	4.41	2.20
	Edging bead 20 cm	2	1	m	7.06	3.53	5.28	2.64
	A wall plug + a screw for an edging bead	100	3	m	9.86	0.30	2.59	0.08
	Apu bead 6mm	2.4	1	m	2.74	1.14	1.96	0.81
	A corner covered with textile	2.5	1	m	1.70	0.68	0.85	0.34

Source: (Karásek, et al., 2018).

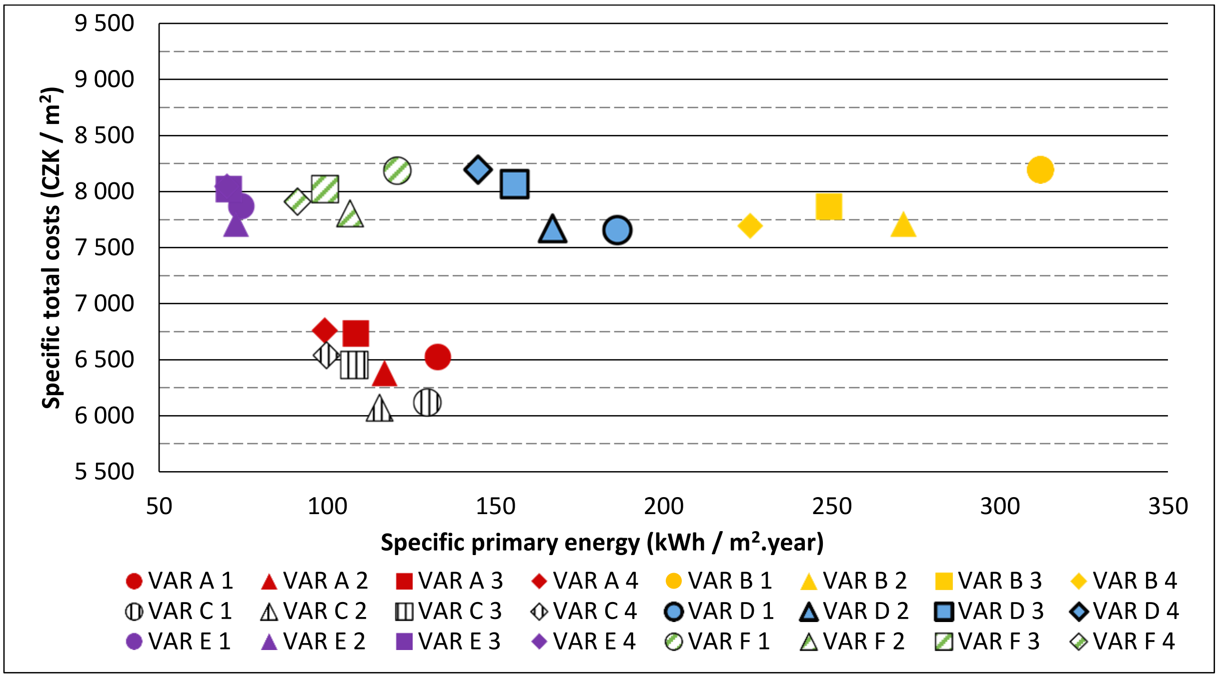


Figure 24: Cost optimization for apartment building (natural ventilation)

Source: (Karásek, et al., 2018).

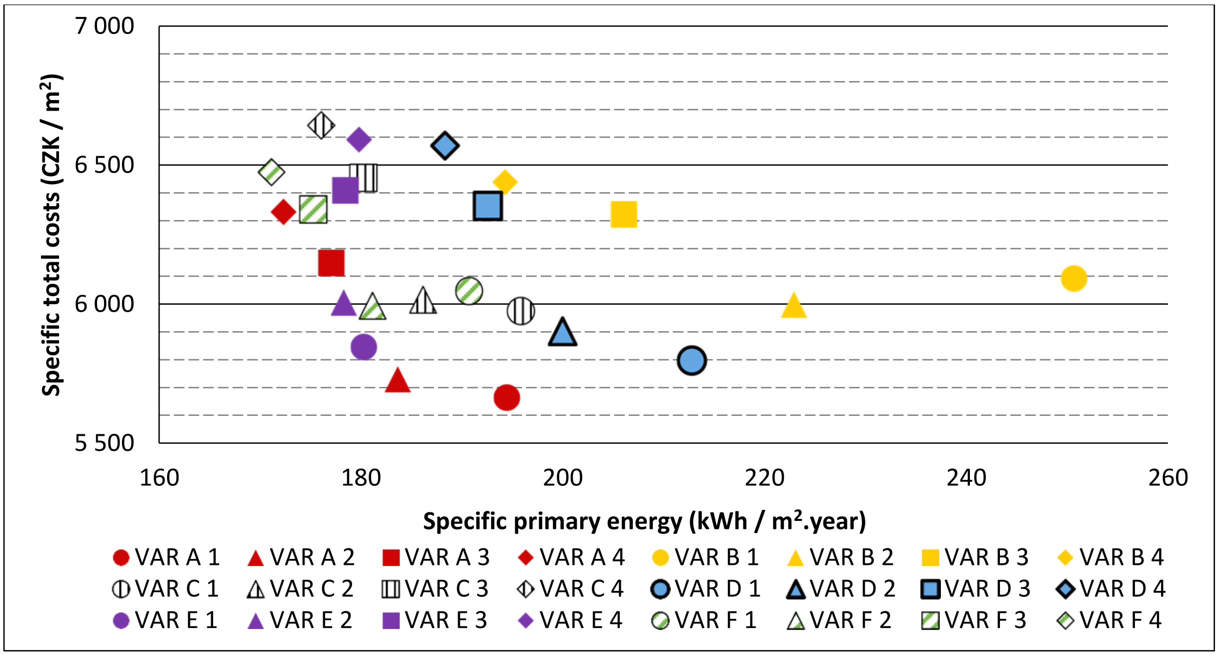


Figure 25: Cost optimization for administrative building (with heat recovery).

Source: (Karásek, et al., 2018).

Like Figure 23, Figures 24 and 25 show the cost optimisation of a selected building. For natural and mechanical ventilation, the best value is achieved using a gas boiler or heat pump. For all heat sources, the optimal values of the building measures with the recommended values of the heat transfer coefficient have been reached.

The graphs indicate that the type of heat source is influenced mainly by the results. The results are also affected by relatively low fuel and electricity prices, and thus low cost savings for the energy consumed.

Coefficients for conversion to primary non-renewable energy affect the results as well. This regards chiefly the biomass boiler and the heat pump. As indicated by Figures 23 – 25 above, the choice of an optimal energy efficiency measure depends largely on energy savings and the cost of investments necessary for the given measure. Therefore, it is essential to provide regular updates of data needed for the calculation of costs.

7.11 Sensitivity analysis

To better explain impact of the input parameters on a specific total costs a sensitivity analysis was carried out based on the recommended values of the building envelope (Decree, 2013) and most common gas boilers. However, similar results would be achieved with the other calculation alternatives.

The essential input values of the calculation are covered by energy price growth (2%) and the discount rate (4%), based on the national legislation. A sensitivity of the specific total costs amounts from 80 to 127%, which is significant and influencing the result. From 2012 to 2016 the energy price dropped to approximately 80 % in the country. It decreases the specific total cost.

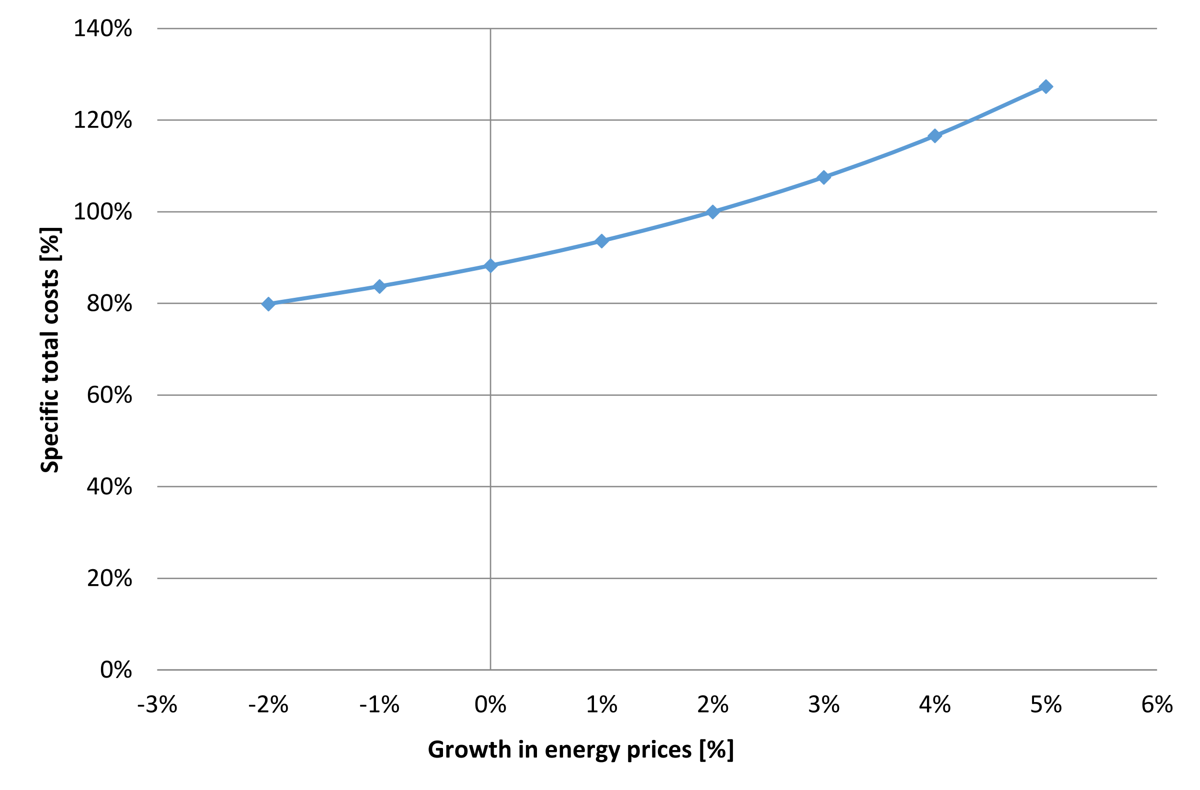


Figure 26: Sensitivity analysis of the energy price change, apartment building.
Source: (Karásek, et al., 2018).

Sensitivity analysis of change in the discount rate of an apartment building

The original values applied are energy price growing by 2% and discount rate amount 4%. A sensitivity of the specific total cost for different discount rates amounts from 199 to 92%.

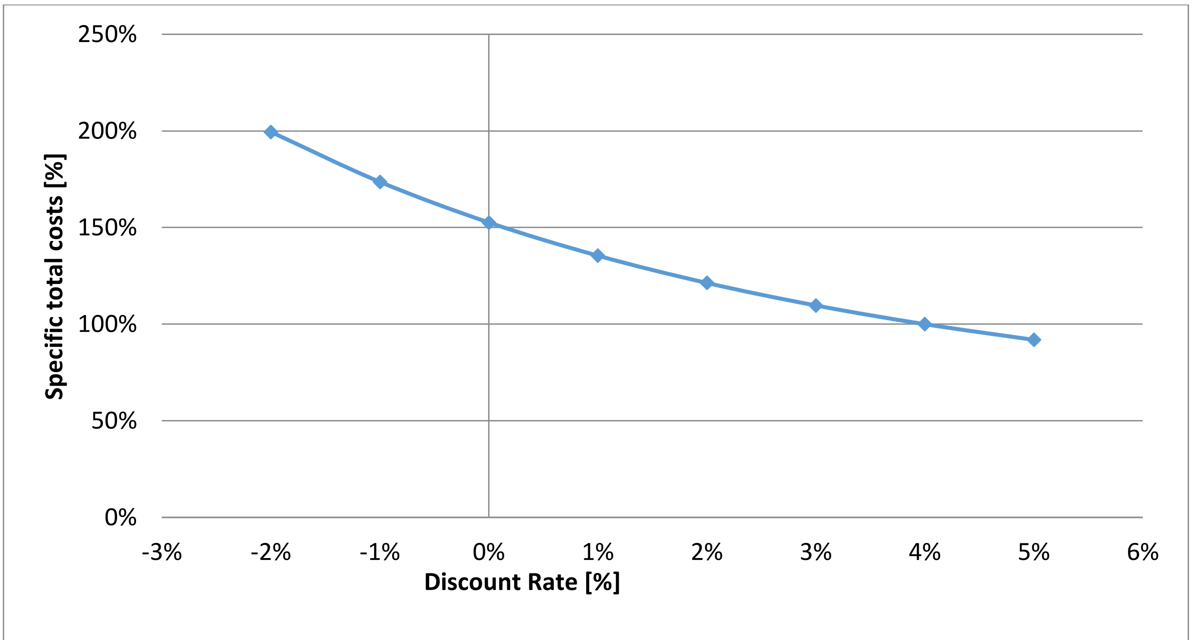


Figure 27: Sensitivity analysis of the change in the discount rate, apartment building.
Source: (Karásek, et al., 2018).

Sensitivity analysis of the change in the investment cost of the apartment building

The input investment cost for the same energy efficiency measures are rather variable. The cost depends mainly on the regional competition and building material availability. Also the individual offers of the companies significantly differ. Such factors are displayed in the sensitivity analysis of the investment cost. It is worth to mentioning that the influence of the investment cost decreases with length of the evaluation period. Sensitivity of the specific total cost by various investment cost amounts only from 99 to 101%.

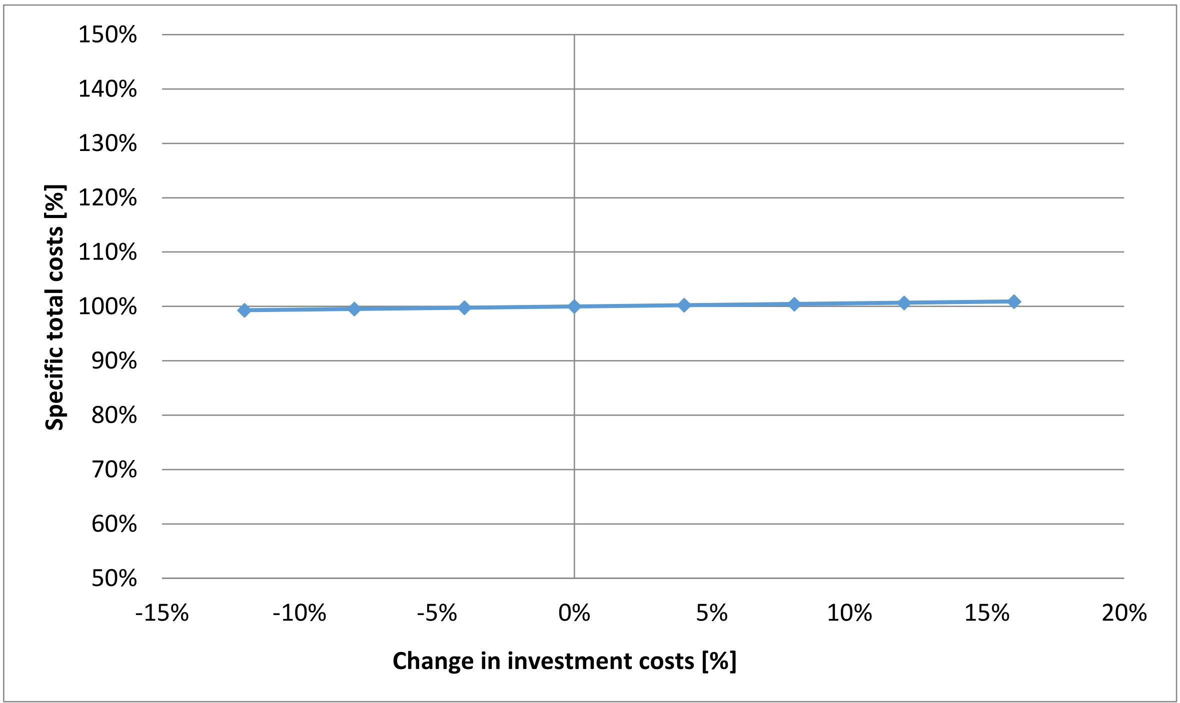


Figure 28: Sensitivity analysis of the change in the investment cost, apartment building.
Source: (Karásek, et al., 2018).

The sensitivity analysis shoved essential impact of the applied discount factor and change of energy price on specific total cost. Change of both parameters by 1% make change of the specific total cost up to 10%. Level of sensitivity of the investment cost is in comparison with the discount rate and price increasing significantly lower, because the investment cost influences the results just ones during the evaluation period. The decision about the discount rate and the energy price growing seems to be crucial for the cost optimum calculations.

8 Suggestions for the supporting programme to tackle energy poverty

Suggestion for the supporting program to tackle energy poverty introduces the main results within a broad range activities later published in Energy Policy Journal as (Karásek & Pojar, 2018), the conceptual map (Annex 1) was published via (Rademaekers, et al., 2016).

8.1 Introduction

Households are increasingly struggling with fluctuating energy prices and this 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 detailed description of energy poverty as well as the lack of strategies aiming at decreasing the occurrence and impact of energy poverty on households. In addition, there is a lack of general awareness of the problem both among professionals and the overall population. Therefore, the first step should be to map out the situation and define particular tasks. A deep causalities of Energy Poverty are described in Annex 1. (Rademaekers, et al., 2016)

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, (EP, 2012), (Act No. 406/2000 Coll., 2000).

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 (MPO, 2017), (Valentová & Honzík, 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, et al., 2012), (Bouzarovski, et al., 2012).

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).

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.

To resolve energy poverty issue, it is necessary to find suitable indicators which display the current state of the art. Household income and expenses, as well as the technical condition of dwellings need to be described. Energy poor households that need government support are detected based on statistics and a comparison of the current situation among the EU Member States. The chapter on methods used includes comparison of selected indicators of energy poverty (Chapter 8.1) as it is crucial to find appropriate indicators to tackle with the problem. The Chapter 8.2 describes a calculation method used to estimate the extent of energy poverty in the Czech Republic. The last part of the chapter describes the method of using statistical data.

8.2 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, et 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.

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. The most suitable indicators have been selected to cover

8.3 Estimation of endangered households

As detailed analysis on energy poor households and their income and structure is still missing in the Czech Republic, an estimation of endangered households is presented in the text. Households were divided into groups according to the type of building:

- Family houses;
- Apartment buildings – panel, brickwork.

Average energy losses and energy consumption have been calculated for various types of buildings. Calculation are based on statistical data, especially floor areas and building envelope data. The households were divided into five income categories. In each category, the average household income was compared to the operational costs of the building.

8.4 The use of statistical data

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, 2015) were used to compare the situation in the UK and the Czech Republic.

8.5 Results

Programmes to tackle energy poverty in the Czech Republic are still underdeveloped, which accounts for the lack of information sources that would help determine the present situation in the country. As a consequence, we can only rely either on foreign analyses or statistical data.

Energy prices strongly influence household expenses. Rising energy prices may cause substantial problems to many households, which will not be able to handle the expenses despite their efforts to save as much energy as possible.

Although general awareness of the problem has risen, energy poverty may still endanger many households. Households may succeed in reducing their energy consumption, but they cannot influence external factors. For example, households are endangered by increasing energy prices that their income is no longer able to cover, meaning they will have to start saving.

Savings in households will probably start with things other than heating, but when these are exhausted, the level of comfort will sooner or later be affected. Another way to decrease energy expenses is to stop heating unused parts of the house, but this leads to damage over time.

8.5.1 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 (MPSV, 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 (MMR, 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 problems 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.

8.5.2 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 & Pavlica, 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, 2013), (SEF, 2018).

8.5.3 Law on Aid for Citizens in Need

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

- Subsidy on costs 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 costs for housing is lower than a minimum value of costs for living. Renting a flat, regular costs for maintenance of the flat and energy costs are considered as adequate costs 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 (MPSV 2011).

8.5.4 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.

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 costs 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 problems, it also addresses the imminent threat of energy poverty head on, as households can improve their energy management and resolve their problems 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 (GOV.UK, 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. Energy suppliers who have to fulfil obligations regarding improvement of the building quality, finance expenses connected with the above measures. 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 (GOV.UK, 2016).

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 combating energy poverty, but can help in case of a protracted increase of energy consumption (GOV.UK, 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, 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 (Domestic Renewable Heat Incentive, 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.

8.6 Estimation of the number of households affected by energy poverty

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 characterize 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, 2015).

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, energy balance was calculated based on the Equation 1.

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 17 show the percentage of households in the given categories whose expenditure exceeds 10% of their income.

Table 17: Estimated number of energy poor households in CR

Estimated percentage of potentially energy poor households based on the type of building	
Type of household:	[%]
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**

Source: (Karásek, et al., 2018).

In Table 17 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 minimized 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.

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.

According to Eurostat statistics a current share of population at risk of poverty or social exclusion (year 2016) is 13.30% in the Czech Republic and 22.20 in the United Kingdome. The EU average is 23.50%. The highest share among the EU countries (around 40% is in Romania and Bulgaria). It means that the share of household at risk of general poverty is lower in the compared countries but the number is still significant (Eurostat, 2017).

8.7 Measures of a draft 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.

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 receiving income from employment;
- One-person households – a household occupied by only one person;
- Single-income households – a household occupied by one or more person, but the household has only one income;
- Incomplete families – a household occupied by one adult person 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. Some existing programmes and schemes in the Czech Republic already deal with these measures, so the problem 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 approach, 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 specialized 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 of the measure. If the measure is well designed, the household will achieve energy and economic savings immediately after the action is taken. Additional financial savings will appear after repayment of the investment.

The design of the program has to be a comprehensive solution of energy poverty, not just a partial one. The program must be incorporated into the national legislation including a national strategy which is still missing in the country. Cooperation with other legislative documents is essential (for example, system of assistance in material need (MPSV, 2015). The program must also co-operate with existing support programmes for reducing energy consumption in buildings.

9 Conclusions

The thesis covers broad range of energy policy evaluations, both ex ante and ex post. The text uses also various methods and calculation of indicators working with analysis of the data collected but also a personal questionnaire needed to understand behavioral aspects of the investors. It is evident that deep analysis of the significant sources allocated in Energy Efficiency and Renewables make sense. Based on the results, a clear recommendation were formulated. However, still the data availability is low to provide full picture of the market and to describe the whole chain introduced in the Chapter one. For each of four case studies, specific conclusions and answering of the research questions is presented.

9.1 Conclusions related to analysis of Green Investment Scheme

The main goal of this study was to evaluate the economic and environmental outputs of the Green Investment Scheme in the Czech Republic and finding the most suitable solution for future projects that aim at reducing GHG and increasing energy efficiency. Data available and data from the IS GIS database of the State Environmental Fund were used for the analysis and evaluation of the Green Savings Programme.

The evaluation of effectiveness of emission reduction was performed using a GHG abatement cost indicator and greening ratio indicator. The lowest and thus most effective values of abatement cost were achieved in the categories of biomass boilers and heat pumps, in the amount of 12 €·t CO_2^{-1}. To the contrary, construction of passive energy standard buildings and installation of solar thermal systems proved ineffective, with values of 272 and 124 €·t CO_2^{-1}, respectively. The area of insulation was also above average with 92 €·t CO_2^{-1}.

Similar results were found in the greening ratio indicator. From the perspective of the effectiveness of financial funds expended towards the reduction of GHG emissions, biomass boilers and particularly the exchange of former heating with fossil fuels to heating with biomass, as well as heat pumps (particularly the air-water technology) were found as the most beneficial solution.

Economic parameters were also analyzed in order to achieve a complete evaluation, in this case using the payback periods indicators. Unlike the effectiveness of the emission reduction, biomass boilers do not achieve payback periods. In other categories of the programme, the simple payback periods range from 11 years (insulation) to 19 years (solar systems). Thanks to the financial subsidy provided, the payback periods for the user drops to 4 years (in case of insulation) and 8 years (in case of solar systems and heat pumps).

As is apparent from the final and complete evaluation, the most suitable subsidy area of the Programme became the area of biomass boilers and heat pumps. From the perspective of the applicants, the most advantageous area was insulation, in which a feasible economic payback was achieved as well as an improvement in the quality of living and appreciation of the property value.

Based on the outputs obtained, the following recommendations are proposed.

- Improving effectiveness of the administrative process and elimination of administrative costs on the part of the applicant;
- Optimum setup of the amount of subsidy (increasing effectiveness of GHG emission reduction).

Administrative costs should become a major indicator of the effectiveness of administering projects. Typically, the Czech Republic is monitored as a whole, but many different types of projects are not monitored. Should the administrative costs of an average application be 520 € (=13,000 CZK) and the smallest types of application for subsidies achieve the value of 2,200 € (=55,000 CZK), it appears that while sustaining the existing method of administration and approval, such administration is ineffective. A change in the structure is proposed in the case of simple measures of exchanging boilers.

We highly recommend monitoring the payback period of measures, as well as their environmental impacts for further continuation of similar programmes. Potentially, this will create locally suitable programmes, for example the replacement of solid fuels in smaller municipalities or programmes for replacing electricity with biomass or heat pumps. When establishing the amount of the subsidy, it is necessary to choose the amount of reduced emissions over economic costs.

In terms of the overall evaluation, it may be said that the payback period of the project does not fully correspond to the level of subsidy of such projects, while the typical goal of subsidy programmes is ensuring the same level of payback for the measures. In most cases, the subsidy of biomass boilers had no economic effect for the user; however, it had a critical and positive effect in replacing solid fuels and local improvement of the environment during the heating season. Similarly, the payback period on solar thermal system is, according to the Programme data, extensive and should therefore be partially compensated by a higher level of subsidy.

Answering related research question

The research question:

Are the energy efficiency and renewable energy indicators a common and useful part of the energy efficiency policy evaluation?

Answer:

Unfortunately, a full range of data needed for calculation and evaluation of the indicators is only available in the Green to Savings Programme, OPŽP programme and in OPPIK programme. In other programmes, such deep data are not collected and are not available. Based on the case study above, such results are useful for setting up of the programme parameters such as the level of subsidy and sources allocated. Moreover, it is useful for evaluation of the programme effectiveness.

9.2 Conclusions related to the Ex-post analysis

The experience with the implementation of the Green Savings Programme has shown that this programme was a new impetus for the development of further energy efficiency projects in the field of residential buildings. The Programme led to an immediate CO_2 reduction and kick-started a long-term trend of sustainable construction. It was also a crucially important and effective instrument for achieving national energy efficiency targets, according to the respective EU directives, e.g. (EP, 2012).

In total, 206 measures were inspected in 124 projects, including combinations of measures. The comparison of ex ante and ex post CO_2 emission savings could be performed with 70 projects (56 % success rate). When the ex post calculation could not be made, the reasons were mostly the unavailability of invoices, low level of detail or the fact that the buildings were not inhabited yet or for a sufficient amount of time (in case of new buildings).

The inspections showed that there is a significant difference between the ex ante savings and ex post savings (25 % on average). The reasons are partly methodical (e.g. calculation methods and norms used for calculation of specific heat demand, inability to cover other heat sources such as fireplaces), but mostly can be attributed to the behavioral factors in the respective buildings. Higher thermal comfort than in the ex ante calculations leads to lower real savings. Similarly, occupancy or patterns of use of the buildings have a high impact on resulting savings. If the buildings are not used fully in a long-term, the measures have much lower-positive impact.

The text demonstrates that the ex post evaluation should be a common part of the energy efficiency programme. Even if the supported projects are small (family houses or building technologies), a sample of applications (units of percent of the whole population) should be selected where the ex-post evaluation is to be carried out. Importantly, such research should be independent of the inspections implemented for the purpose of legal requirements (avoiding deceptions). Only in such case there can be a useful cooperation between the building owner and the research team.

The results of the study open the relationship between calculated and measured savings. As only calculated savings are available before the project implementation, it is necessary to keep it. However, the measured savings are those used in the national energy balance and in targets set up according to Article 7 of Energy Efficiency Directive. It means that rules or calculations taking into account the behaviour of the building user should be set up.

A significant amount of financing has been available under the Green Investment Scheme in the Czech Republic. However, the results have confirmed that a careful evaluation of the supported projects is needed in order to optimize the programmes and to see the actual effects thereof.

Answering a related research question

The research question:

What are the main barriers of the fulfilment of the national EE target in the Czech Republic?

Answer:

Within the case study, a full arrange of barriers was found, e.g. the difference between calculated and measured savings, behavioral aspects e.g. indoor temperature, number of heated rooms and quality of the construction works including lack of experience with the new complex technologies and poor quality of construction works. With this respect an opening of the Programme for self-help works is disputable. All these aspects are influencing aggregate demand for Energy Efficiency.

9.3 Conclusion to cost optimum calculation

The catalogue prices of products and work differ significantly from the final real prices, meaning it is necessary to choose the right information source when updating the data. Therefore, a more accurate model can be achieved to reflect the real state of the building materials market which substantially affects the total costs of energy efficiency measures.

Based on definitions of the measures chosen, the costs of individual measures have been defined as well as their impact on energy consumption in a building. Subsequently, economic parameters of each measure as well as their mutual synergies were calculated. The results should serve primarily as a basis for the calculation of the cost optimum on the national level. The data can also be used for a comparison of cost-related measures between particular EU Member States. In addition, the data can be used when calculating the payback period of the measures proposed because more accurate input data influences the investment cost and consequently the payback period as well.

The result covers prices only for some selected products and works. Further research should focus on other inputs which influence the cost of measures. To ensure a statistically more accurate result, the range of products should be extended and more suppliers should be addressed.

Despite its relatively small size compared to other countries, the Czech Republic should focus on the national distribution of suppliers, producers and materials. Maps indicating local products should be created, which would result in savings in transport to construction sites and reduction of the total cost of measures.

The cost optimum calculation should be applied more often when designing supporting schemes and legislation in the EU Member States. It would reduce levelized cost of the energy efficiency and RES measures significantly.

Answering related research question

The research question:

What are the cost optimal measures that are reducing energy consumption in the Czech Republic?

Answer:

The cost optimal measures depend on many aspects, like energy price, price of EE measures, archived energy savings, evaluation period etc. However, in most cases the recommended values of U coefficient were the cost optimal values with gas or a heat pump as a heat source. A mechanical ventilation makes sense mainly from the indoor-air quality point of view; a financial benefits of the mechanical ventilation are low.

9.4 Conclusion to energy poverty

The existing measures undertaken in the Czech Republic should contribute to reducing energy poverty, yet the problem has received less attention than it deserves. According to the model covering technological and economic part of the topic, the number of households under level of energy poverty is 16%, which is rather high. In reaction to that, strategic goals should be set up in the field of energy poverty including the national definition and the National strategy to tackle energy poverty in the country. Specifically, the Strategy should be developed and adopted in a short period. Consequently, national monitoring indicators evaluating energy poverty in the country should be set up. The most relevant indicators were introduced in the text.

The Czech Republic has got a wide range of experience n supporting schemes in the field of energy efficiency, i.e. there is an opportunity to design a successful programme tackling energy poverty. However, programmes and state schemes initiated in the Czech Republic support the decrease of energy consumption but do not address the issue of energy poverty. The programmes may only work for households as preventive measures against energy poverty. Government housing and social housing benefits play a great role in the issue, but only succeed in rebalancing household budgets. Moving into a more energy efficient flat resolves the situation of a single family, but the problem of the original energy inefficient flat remains unresolved.

It can be assumed that energy prices will rise in a long-term period again and the number of energy poor households will increase. Households and the housing funds in the Czech Republic should be well prepared for this situation. Timely assistance can save a significant amount of primary energy and improve and/or maintain the living standards of households. Broadening the scope of the energy poverty issue and introducing programmes aimed at its reduction should be one of the key measures in the Czech Republic.

This work has a specific impact on the National Strategy of Fight against Energy Poverty which should be introduced within the next few years. Consequently, the Ministry of Industry and Trade leads an inter-ministerial panel for energy poverty issues. Those initiatives should lead to the opening of energy poverty on the governmental level independently of the poverty topic. The official national definition of Energy poverty is still missing in the country. However, a discussion on the definition in the EU countries has been opened. The text should bring new information both to the National programme (to tackle energy poverty) and national definition. On the international level the proposed steps are applicable in many Eastern Europe countries.

Answering related research question

The research question:

Is there any replicable approach in the EU countries suitable for reducing energy poverty of vulnerable consumers in the Czech Republic?

Answer:

Based on the collected experience, there are many replicable approaches around Europe. However, all of them are struggling with a national definition of energy poverty, which still has not I been adopted in the Czech Republic. The development of the national strategy and its implementation is the next step. Based on the strategy, supporting programmes archiving energy savings by vulnerable consumers should be developed.

9.5 Fulfilment of research objectives

As part of the conclusions´ chapter, a fulfillment of the research objectives is examined. At the introductory part a following research objectives have been set up:

- Support of the policy making process for various groups of stakeholders and creation of an information channel from the experts to the policymakers, particularly in technical, economic and legislative issues.

The case studies in the Chapters 5-8 support the target groups via broad range of information about impact and price of various EE and RES measures. In parallel, the recommendations for the policy makers were introduced.

- Create recommendations aiming at strengthening legislative framework especially in the field of the penetration of nearly zero energy buildings and deep renovations of the existing building stock. A special focus is being laid on the recasts of the EPDB and EED directives.

This objective was fulfilled mainly through the study on Cost optimum, which was used as the national cost optimum calculation according to EE Directive. Moreover, such calculations were used as a support of the parts 8.1 and 8.2 of the National housing strategy.

- Develop proposals of the policies addressing energy poverty as one of the potential sources of energy savings. Furthermore, strategies are to be developed to tackle energy poverty via EE mechanisms as vulnerable consumers households are not, by definition, targeted by supporting schemes and thus the energy saving potential is not used at present.

The energy poverty as newly analyzed topic in the Czech Republic was introduced and the national approaches were compared with the international experience. There are still many steps to be done to help energy poor households and to implement National strategy to tackle with energy poverty. However, the study introduced could be a first important step.

9.6 Application of the results for the development and technical practice in the field

Participation of the Department of Construction Management and Economics in energy sector (e.g. via Setur turbine development and activities of the author within the energy efficiency policy evaluation) and putting the energy efficiency in priorities of further research, brought the opportunity to be invited in various projects' proposals. The Department was invited in two H2020 proposals in 2016. In 2017, the Department successfully started Fit-to-nZEB project aiming to the new training programmes in deep retrofitting of the buildings. Later, in 2018, the department was invited to CraftEdu H2020 project coordinated by the author of the thesis. Most of the results introduced here passed the full reviewing process (lasting usually more than one year). Currently, they are presented in four research articles; three in Energy Policy and one in WENE Energy and Environment. There are more articles written in this field by the author. However, as they have not passed the reviewing process yet, the results are not presented in the thesis.

Data collected on energy efficiency and housing is used by the European Commission to set up new energy efficiency policies. The results of the collection are publicly available via database of the EU Building Stock Observatory. Moreover, a huge amount of training materials including full study programmes for nZEBs and deep energy retrofits has been developed. The training materials are being used by the universities, professional high schools and the training centers. It will help to prepare next generation of builders for the structural changes in the construction industry.

Further research possibilities

The research should further continue in developing a comprehensive set of indicators to be used over the supporting programmes in the Czech Republic. Secondly, there is a need for new update of the cost optimal calculations, because there is a significant change in price of technologies, price of energy and price of EE measures. Submission of the proposal for THETA research programme was the first step.

9.7 Impact of the work

The work has an impact on the pedagogic activities of the Department of Construction Management and Economics. Since 2012, courses for bachelor and master students on Energy management of buildings have been introduced (Codes: 126YEMB, 126YEMG). Two new doctoral theses started in the field of Energy Poverty and Energy Management in buildings. Moreover, a training center for nearly zero energy buildings has been opened. In total, 747 trainees passed the center from 2017 to 2019 including many students of the Czech Technical University in Prague. The educational activities will continue further within CraftEdu H2020 project until 2021.

10 References

Act No. 406/2000 Coll., 2000. Act on Energy Management. The Collection of Laws of the Czech Republic, pp. 5314-5319.

HBS, 2010. HBS. Household Budget Survey: Database. Eurostat: European Commission..

Beran, V., Macek, D., Měšťanová, D., 2010. *Výběr konstrukčních řešení a stavebních materiálů na základě modelových přístupů* [Selection of design solutions and construction materials on the basis of model approaches], Prague: Czech Technology - Technical University Publishing House.

Bogenstätter, U., 2000. Prediction and optimization of life-cycle costs in early design. Building Research & Information, 9, 28(5-6), pp. 376-386.

Bouzarovski, S., Petrova, S. & Sarlamanov, R., 2012. Energy poverty policies in the EU: A critical perspective. Energy Policy, Svazek 49, pp. 76-82.

BPIE, 2010. Cost Optimality: Duscussing methodology and challenges within the recast Energy Pervormance of Buildings Directive. The Buildings Performance Institute Europe - (BPIE).

BPIE, 2013. Implementing the Cost-optimal Methodology in EU Countries. Buildings Performance Institute Europe (BPIE).

Carley, S. & Browne, T. R., 2013. Innovative US energy policy: a review of states' policy experiences. Wiley Interdisciplinary Reviews: Energy and Environment, 9, 2(5), pp. 488-506.

Clinch, J. & Healy, J. D., 2001. Cost-benefit analysis of domestic energy efficiency. Energy Policy, 29(2), pp. 113-124.

ČSN 73 0540-2, 2011. : Tepelná ochrana budov – Část 2: Požadavky (Thermal protection of buildings – Part 2: Requirements). Czech Republic.

ČSN 73 0540-2, 2011. Thermal protection of buildings – Part 2: Requirements. Czech technical standards.

ČSN EN 15459, 2010. : Energetická náročnost budov (Energy performance of buildings) - Postupy pro ekonomické hodnocení energetických soustav v budovách. Czech Republic.

ČSN EN 15459, 2010. Energy performance of buildings - Economic evaluation procedure for energy systems in buildings. Czech technical standards.

ČSN EN ISO 13790, 2009. : Energetická náročnost budov - Výpočet spotřeby energie na vytápění a chlazení (Energy performance of buildings - Calculation of energy consumption for heating and cooling). Czech Republic.

ČSN EN ISO 13790, 2009. Energy performance of buildings - Calculation of energy consumption for heating and cooling. Czech technical standards.

ČSN ISO 15686-5, 2014. : Budovy a jiné stavby - Plánování životnosti - Část 5: Posuzování nákladů životního cyklu (Buildings and constructed assets - Service-life planning - Part 5: Life-cycle costing). Czech Republic.

ČSN ISO 15686-5, 2014. Buildings and constructed assets - Service-life planning - Part 5: Life-cycle costing. Czech technical standards.

CSO, 2015 [Online]. Available at: https://www.czso.cz/

D'Agostino, D. & Parker, D., 2018. Data on cost-optimal Nearly Zero Energy Buildings (NZEBs) across Europe. Data in Brief, Svazek 17, pp. 1168-1174.

Davis Langdon, 2007. Life cycle costing (LCC) as a contribution to sustainable construction, Guidance on the use of the LCC Methodology and its application in public procurement.

Decree 78/2013: Vyhláška o energetické náročnosti budov (Decree on Energy Performance of Buildings) (2013). (Next recast expected in April 2019)

Decree, 2013. Decree No. 78/2013 Coll. on Energy Performance of Buildings. The Collection of Laws of the Czech Republic.

Delmastro, C., Mutani, G. & Corgnati, S. P., 2016. A supporting method for selecting cost-optimal energy retrofit policies for residential buildings at the urban scale. Energy Policy, Svazek 99, pp. 42-56.

Den, X. L. a další, 2016. Evaluating EU Cohesion Policy Funding for Energy Efficiency Investments in Public and Residential Buildings Across EU Member States.

Directive 2002/91/EC, 2002. on the energy performance of buildings. Official Journal of the European Communities.

Directive 2010/31/EU, 2010. on the energy performance of buildings (recast) ***I (2010/C 184 E/65). Official Journal of the European Union, pp. 263-291.

EC, 2016. Clean Energy For All Europeans. Svazek COM/2016/0, p. 13.

ECOFYS, 2015. Assessment of cost optimal calculations in the context of the EPBD (ENER/C3/2013-414): Final report. [Online] Available at: https://ec.europa.eu/energy/sites/ener/files/documents/Assessment%20of%20cost%20optimal%20calculations%20in%20the%20co-text%20of%20the%20EPBD_Final.pdf

EEA, 2011. Greenhouse gas emissions in Europe: a retrospective trend analysis for the period 1990–2008. EEA Report, 2011(6).

EN 15217 Energy performance of buildings – Methods for expressing energy performance and for the energy certification of buildings, currently replaced with EN ISO 52003-1 (730324) Energy performance of buildings -- Indicators, requirements, ratings and certificates -- Part 1: General aspects and application to the overall energy performance

EN 15459 Energy performance of buildings – Economic evaluation procedure for energy systems in buildings;

EN 15603 Energy performance of buildings – Overall energy use and definition of energy ratings; currently replaced with EN ISO 52000-1:2017 Energy performance of buildings -- Overarching EPB assessment -- Part 1: General framework and procedures and ISO/TR 52000-2:2017 (2017) Energy performance of buildings -- Overarching EPB assessment -- Part 2: Explanation and justification of ISO 52000-1;

EN 15316 Heating systems in buildings;

EN ISO 6946 Building components and building elements – Thermal resistance and thermal transmittance – Calculation method;

EN ISO 13790 Energy performance of buildings – Calculation of energy use for space heating and cooling, currently replaced with ISO 52016-1:2017 Energy performance of buildings -- Energy needs for heating and cooling, internal temperatures and sensible and latent heat loads -- Part 1: Calculation procedures;

EN ISO 13789 Thermal performance of buildings – Transmission and ventilation heat transfer coefficients – Calculation method;

EN ISO 13370 Thermal performance of buildings – Heat transfer via the ground – Calculation methods.

ENTRANZE, 2012. Working paper: Literature review of key stakeholders, users and investors: D2.4. of WP2 of the Entranze Project.

EP, 2003. Directive 2002/91/EC on the energy performance of buildings. Official Journal of the European Communities.

EP, 2010. Directive 2010/31/EU on the energy performance of buildings (recast). Official Journal of the European Union, L153/13(18.6.2010), pp. 13-35.

EP, 2012. Directive 2012/27/EU on energy efficiency, amending Directives 2009/125/EC and 2010/30/EU and repealing Directives 2004/8/EC and 2006/32/EC. Official Journal of the European Union, 14/11/2012(October 2012), pp. 1-56.

EP, 2016. Winter Package. [Online]. Available at: https://ec.europa.eu/energy/en/topics/energy-strategy-and-energy-union/clean-energy-all-europeans

European Commission Report: REPORT FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT AND THE COUNCIL - Progress by Member States in reaching cost-optimal levels of minimum energy performance requirements (2016).

Eurostat, 2017. Your key to European statistics. [Online]. Available at: https://ec.europa.eu/eurostat/web/products-catalogues/-/KS-02-17-839?inheritRedirect=true

Ferrara, M. & Fabrizio, E., 2017. Cost optimal nZEBs in future climate scenarios. Energy Procedia, Svazek 122, pp. 877-882.

Flanagan, R., Norman, G., Robinson, G. & Meadows, J., 1989. Life Cycle Costing Theory and Practice. Oxford: Blackwell Science Ltd.

Fleiter, T., Hirzel, S. & Worrell, E., 2012. The characteristics of energy-efficiency measures – a neglected dimension. Energy Policy, 51(-), pp. 502-513.

GOV.UK, 2016. Cold Weather Payment. [Online]. Available at: https://www.gov.uk/cold-weather-payment

GOV.UK, 2016. Green Deal: energy saving for your home. [Online]. Available at: https://www.gov.uk/green-deal-energy-saving-measures

GOV.UK, 2016. Winter Fuel Payment. [Online]. Available at: https://www.gov.uk/winter-fuel-payment

Guardigli, L. a další, 2018. Energy retrofit alternatives and cost-optimal analysis for large public housing stocks. Energy and Buildings, Svazek 166, pp. 48-59.

Heralova, R. S., 2014. Life Cycle Cost Optimization Within Decision Making on Alternative Designs of Public Buildings. Procedia Engineering, Svazek 85, pp. 454-463.

Hills, J., 2012. Getting the measure of fuel poverty: Final Report of the Fuel Poverty Review. CASE report 72, p. 237.

Honzík, M., Karásek, J. & Chmel, P., 2013. Groundwork for Energy Efficiency Action Plan. SEVEn, o.p.s..

Hromada, E., 2016. Real Estate Valuation Using Data Mining Software. Procedia Engineering, Svazek 164, pp. 284-291.

Chegut, A., Eichholtz, P. & Holtermans, R., 2016. Energy efficiency and economic value in affordable housing. Energy Policy, 97(-), pp. 39-49.

Jakob, M., 2006. Marginal costs and co-benefits of energy efficiency investments: The case of the Swiss residential sector. Energy Policy, 34(2), pp. 172-187.

Karásek, J., 2013. Comprehensive EE policy for the Republic of Belarus. Praha: SEVEn.

Karásek, J. & Pavlica, J., 2016. Green Investment Scheme: Experience and results in the Czech Republic. Energy Policy, 90().

Karásek, J. & Pavlica, J., 2016. Policy strategies leading to deep renovations. CESB conference. Prague.

Karásek, J. & Pojar, J., 2018. Programme to reduce energy poverty in the Czech Republic. Energy Policy, 1 4, Svazek 115, pp. 131-137.

Karásek, J., Pojar, J., Kaločai, L. & Heralová, R. S., 2018. Cost optimum calculation of energy efficiency measures in the Czech Republic. Energy Policy, 1 12, Svazek 123, pp. 155-166.

Kovacic, I. & Zoller, V., 2015. Building life cycle optimization tools for early design phases. Energy, Svazek 92, pp. 409-419.

MMR, 2016. 117D0640 Podporované byty 2016. Ministry of Regional Development CZ.

Moore, R., 2012. Definitions of fuel poverty: Implications for policy. Energy Policy, Svazek 49, pp. 19-26.

MPO, 2017. National Action Plan for Energy Efficiency of the Czech Republic. Ministry of Industry and Trade of the Czech Republic.

MPSV, 2015. Concept of Social Housing of the Czech Republic 2015-2025. Prague: Ministry of Labour and Social affairs.

Rademaekers, K. a další, 2016. Selecting indicators to measure energy poverty: Final Report. Rotterdam: Trinomics B. V..

Regulation 244/2012, 2012. [Online]. Available at: https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2012:081:0018:0036:EN:PDF

Ryghaug, M. & Sørensen, K. H., 2009. How energy efficiency fails in the building industry. Energy Policy, 37(3), pp. 984-991.

Samuelson, P. A., & Nordhaus, W. D. (2012). Economics (19th ed.). New Delhi: Tata McGraw Hill Education Private Limited.

Sayeg, P. & Bray, D., 2012. Estimating changes in emissions from bus rapid transit: making best use of transport sector experience. Wiley Interdisciplinary Reviews: Energy and Environment, 11, 1(3), pp. 308-316.

SEF, 2013. Annual Report of The Green Investment Scheme Programme 2012. Prague: State Environmental Fund of the Czech Republic.

SEF, 2018. New Green Savings Programme.

SFRB, 2013. Program Panel 2013+: Loan program for the revitalization of the housing stock, regardless of the construction technology.

Sovacool, B. K., 2015. Fuel poverty, affordability, and energy justice in England: Policy insights from the Warm Front Program. Energy, Svazek 93, pp. 361-371.

TABULA, 2016. IEE Project TABULA (2009 - 2012).

Trianni, A., Cagno, E. & De Donatis, A., 2014. A framework to characterize energy efficiency measures. Applied Energy, 118(-), pp. 207-220.

Tuerk, A. a další, 2010. Working Paper Green Investment Schemes. Joanneum research, Institute of Energy Research, Graz, Austria.

UN, 2015 United Nations Climate Change Conference, COP 21 or CMP 11.

UN, 2016. Sustainable Development Goals. [Online] Available at: https://news.un.org/en/story/2016/03/524202-un-statistical-body-agrees-global-indicators-measure-sustainable-development

UN, 1998. Kyoto protocol to the United Nations Framework Convention on Climate Change. UNITED NATIONS.

UNFCCC, 2008. Kyoto protocol reference manual. 1 editor United Nations Framework Convention on Climate Change: Information Services of the UNFCCC secretariat.

Valentová, M. & Honzík, M., 2011. Study: transaction costs of energy efficiency programs. Praha: SEVEn, The Energy Efficiency Center.

Valentová, M., Karásek, J. & Knápek, J., 2018. Ex post evaluation of energy efficiency programs: Case study of Czech Green Investment Scheme. Wiley Interdisciplinary Reviews: Energy and Environment, 17 8.p. e323.

Waddams Price, C., Brazier, K. & Wang, W., 2012. Objective and subjective measures of fuel poverty. Energy Policy, Svazek 49, pp. 33-39.

Webber, P., Gouldson, A. & Kerr, N., 2015. The impacts of household retrofit and domestic energy efficiency schemes: A large scale, ex post evaluation. Energy Policy, Svazek 84, pp. 35-43.

Yazdanie, M., Densing, M. & Wokaun, A., 2017. Cost optimal urban energy systems planning in the context of national energy policies: A case study for the city of Basel. Energy Policy, Svazek 110, pp. 176-190.

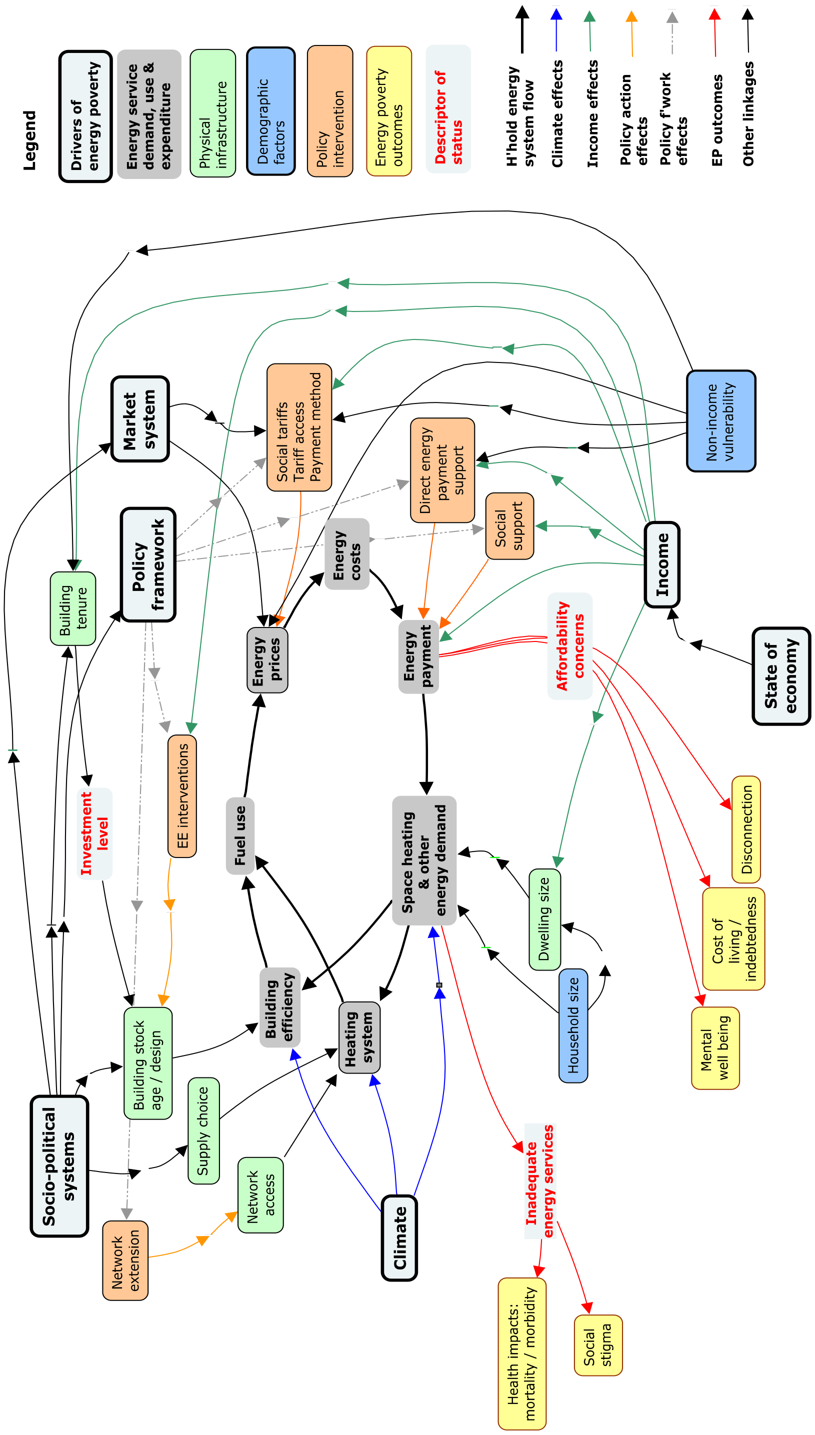
11 List of tables

12 List of figures

13 List of equations

14 Annexes

Annex 1, Conceptual map of the drivers, causes and effects of energy poverty



Annex 2, Overview of the political measures based on Article 7, of Energy Efficiency Directive

Measure number 2.2	Measure	Achieved savings			Expected savings[10]	Total savings	Allocation (expected)
		2008-2010	2011-2013	2014-2016	2017-2020	2014-2020	2014-2020
		TJ	TJ	TJ	TJ	TJ	CZK
Implemented measures to support energy savings							
1.1	Regeneration of pre-fabricated concrete buildings – PANEL, NEW PANEL (Ministry of Regional Development) and PANEL 2013+ Programmes	-	-	106.9	100	206.9	4.5
1.2	Green Savings Programme (Ministry of the Environment)	2,950	2,950	-	-	-	-
1.3	New Green Savings Programme 2013 (Ministry of the Environment)	-	-	311.3	-	311.3	0.55
1.4	New Green Savings Programme 2014-2020 (Ministry of the Environment)	-	-	734.8[11] (2,710)	7,855[12]	10,565	19.36
1.5	JESSICA Programme (Ministry of Regional Development)	-	-	73.9	-	73.9	0.6
1.6	Integrated Regional Operational Programme (Ministry of Regional Development)	-	-	0	3,100	3,100	16.9
1.7	Joint Boiler Replacement Scheme (Ministry of the Environment)	-	-	49.6	-	49.6	-
1.9	Operational Programme Environment 2014-2020 (Ministry of the Environment) (Priority Axis 2 – SO 2.1)	-	-	817.2	2,300	3,117	10
1.8	Operational Programme Environment 2007-2013 (Ministry of the Environment)	139	1,168	2,060	-	2,060	-
1.9	Operational Programme Environment 2014-2020 (Ministry of the Environment) (Priority Axis 5 – SO 5.1)	-	-	0.00	1,500	1,500	14.6
1.10	State programmes to promote energy savings and the use of renewable energy sources (EFEKT) (Ministry of Industry and Trade)	165	21	28.4	-	28.4	0.1
1.11	State programme to promote energy savings (EFEKT 2) (Ministry of Industry and Trade)	-	-	-	400	400	0.6
1.12	OP Prague Growth Pole – buildings section (City of Prague)	-	-	0	10	10	1
1.13	Operational Programme Enterprise and Innovation 2007-2013 (Ministry of Industry and Trade)	1,569	4,000	2,098.8	-	2,098.8	-
1.14	Operational Programme Enterprise and Innovation for Competitiveness 2014-2020 (Ministry of Industry and Trade)	-	-	19	9,600	9,619	20
1.15	ENERG Programme (Czech-Moravian Guarantee and Development Bank)	-	-	-	40	40	0.13
1.16	Reasonable Energy Savings Programme (Ministry of Industry and Trade)	-	-	-	-	-	-
1.17	Alternative measures for increasing energy efficiency in Czech industry and in municipalities and regions	-	-	100	400	500	-
1.18	Operational Programme Transport (Ministry of Transport)	-	-	-	21	21	-
1.19	Strategic Framework for Sustainable Development	-	-	10,645	5,200	15,845	-
Total		**4,823**	**8,139**	**17,045**	**30,526**	**49,546**	**88.3**
The potential introduction, setting and evaluation of measures will take place during 2017-2020							
1.20	Promoting the Eco driving of cars				200		
1.21	Organization of Eco driving training for lorry and bus drivers				1,800		
1.22	Support for the installation of cogeneration units				600		
1.23	Energy Savings Fund				2,600		
1.24	Support for the construction sector in the Czech Republic is improving energy efficiency and environmental protection in line with the EU 2020 environmental strategy				1,000		
1.25	Programmes supporting research and development						
1.26	Summary of measures to increase the energy efficiency of agricultural plants						
Total					**6,200**		

Annex 3, Questionnaire of ex post evaluation

<table>
<tr><td colspan="2" align="center">Protocol of the on-site inspection</td></tr>
<tr><td colspan="2" align="center">Identification of applicant</td></tr>
<tr><td colspan="2">Identification No of application</td></tr>
<tr><td colspan="2">Applicant</td></tr>
<tr><td colspan="2">Type of applicant</td></tr>
<tr><td colspan="2">Address</td></tr>
<tr><td colspan="2">Region</td></tr>
<tr><td colspan="2">Type if building</td></tr>
<tr><td colspan="2">Code of EE measure</td></tr>
<tr><td colspan="2">1. Administration part of inspection</td></tr>
<tr><td colspan="2">Findings related to the administrative part of the project or related to the contractor.</td></tr>
<tr><td align="center">Availability of the invoices for energy after implementation of EE measures:</td><td></td></tr>
<tr><td colspan="2">2. Physical part of inspection</td></tr>
<tr><td colspan="2">Findings related to the physical part of inspection:</td></tr>
<tr><td colspan="2">Description of the figures included as an annex of the protocol:</td></tr>
<tr><td colspan="2">3. Results of inspection</td></tr>
<tr><td colspan="2">Overall evaluation:</td></tr>
</table>

Results of analysis; energy consumption evaluation of heating hot water preparation after implementation measures in case of energy invoices available:
Signature of head of inspection group
Energy expert signature
Applicant signature