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2016 **Lucie Častorálová**

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Thermal Insulation in Apartment Buildings: Decision-making Process and Effect on Energy Savings

Bachelor thesis

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Author: Lucie Častorálová

Supervisor: Mgr. Milan Ščasný, Ph.D.

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Declaration of Authorship

The author hereby declares that she compiled this thesis independently, using only the listed resources and literature. This thesis was not used to obtain another academic degree.

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Prague, May 10, 2016

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Abstract

In order to lower the emissions of green-house gases it is necessary to explore the wide range of the energy efficiency options. This thesis attempts to analyse the effect of thermal insulation installed in the multi-family apartment buildings during the period of 2006-2012 in the Czech Republic. We also investigate whether providing governmental funding further improves energy performance of the insulated apartment buildings. In addition, we examine the collective decision-making processes of members of the multi-family apartment building associations, including their attitudes towards thermal insulation of their houses. The basis of this thesis is the econometric panel data model (with 45 apartment buildings and their energy consumption before and after the insulation) evaluated by the fixed effects method with cluster confirming that the insulation, investments and public funding had all significant and negative impact on the energy consumption in the buildings, when energy consumption was adjusted for weather conditions. After the analysis it was concluded that the more the owners invest in thermal insulation, the more they will save in the long run. The governmental funding led to even greater energy savings and the grants that offer better interest rates on loans are more efficient than the others. Our evidence also supports the notion that the energy savings are lower in those apartment buildings that were insulated at a later stage, as opposed to the apartment buildings that were insulated earlier. The more time passed after the insulation, the less the owners typically saved for heating and that may point at rebound effect.

Key words: associations of unit owners, energy consumption for heating**,** energy efficiency, energy savings, government grants, heating degree days, rebound effect, thermal insulation

Author's email: lucie.castoralova@gmail.com

Supervisor's email: milan.scasny@czp.cuni.cz

Abstrakt

V souvislosti se snižováním produkce skleníkových plynů je zapotřebí vyřešit otázku vysoké spotřeby energie a využít celkové možnosti energetických úspor. Tato práce zkoumá energetickou efektivitu provedených opatření zateplení bytových domů v České republice v období mezi lety 2006 a 2012. Práce dále hodnotí úspěšnost dotačních programů zaměřených na snižování energetické náročnosti budov, hlavně z hlediska vlivu těchto programů na další energetické úspory. Jejím cílem je také analyzovat způsob rozhodování společenství vlastníků jednotek a zjistit jejich názor na zateplování bytových domů. Základem výzkumu je ekonometrický model využívající panelová data (obsahující 45 bytových domů a jejich spotřeby energií na vytápění před a po zateplení), která jsou vyhodnocena pomocí metody fixních efektů s klastrem a potvrzují záporný vliv realizace zateplení, investice i dotace na spotřebu energie očištěnou o vliv počasí. Analýzou byl učiněn závěr, že čím více lidé investují do zateplení, tím více ve výsledku ušetří. Státní dotace přispívá k ještě vyššímu poklesu spotřeby energií. Dotace zaměřené na poskytování výhodnějších úrokových sazeb v rámci půjčky jsou úspěšnější než ty ostatní. Tato data také přispívají k názoru, že energetické úspory bytových domů, které byly zatepleny v poslední době, jsou nižší než u domů zateplených dříve. Lidé se s odstupem času po zateplení jejich domu chovají méně hospodárně, projevuje se zpětný efekt, tedy vyšší energetická účinnost pobízí lidi k další spotřebě.

Key words: společenství vlastníků jednotek, spotřeba energie na vytápění, energetická účinnost, energetické úspory, státní dotace, meteorologické denostupně, efekt zpětného rázu, zateplení

Author's email: lucie.castoralova@gmail.com

Supervisor's email: milan.scasny@czp.cuni.cz

Bachelor thesis proposal

Author	Lucie Častorálová
Supervisor	Mgr. Milan Ščasný, Ph.D.
Proposed topic	Thermal Insulation in Apartment Buildings: Decision-making Process and Effect on Energy Savings

Research question and motivation The topic of revitalization of old block of flats has become largely discussed in the last decade, especially in Central and Eastern European countries with their long tradition in building them since the 1960's. The European Union has stated the requirement for energy efficiency of buildings. That is why residents have started to restore their housing to satisfy this requirement.

In the case of cooperative ownership of dwelling, the rights to perform large investment in building are shared among the dwelling unit owners and the decision is taken either by the management board or through a voting procedure. Majority rule may be a main obstacle for adopting efficient technologies such as thermal insulation of the building. There might be other sources of obstacles such as the lack of information when making decisions.

The association of unit owners often have to apply for the loans in a bank or another financial institution. Some of the associations of unit owners accomplished the reconstruction of their apartment building or block-of-flats by using the financial aid of subsidies like The Green for Savings Programme, Panel Programme and others, which at least partly covered the costs needed to achieve the reconstruction.

The first problem that will be analysed is a decision-making process of associations of unit owners about thermal insulation of the apartment building. We plan to investigate what motivated associations of unit owners to insulate their building, what were the main obstacles to reach consensus and what argument was mainly raised by the owners who were not willing to consent to proposed reconstruction project. Furthermore, we examine whether associations of unit owners did consider taking a loan to fund the reconstruction (especially thermal insulation), whether they obtain a subsidy, how large is their repair fund and how much are associations of unit owners´ members used to contributing to it. After assuming for these factors we probe into what was their decision to undergo reconstruction of their apartment building and how would they change their mind if there was not possibility to obtain any subsidy or if the quantity of the subsidy was reduced.

A central point of our qualitative investigation is an investigation of possible factors of the energy efficiency gap (Gerarden 2015; Jaffe and Stavins 1994) related to decision about insulation of apartment buildings. Particularly, we will investigate whether expected energy savings due to insulation and hence savings in energy costs were taken into account in the decision-making process and what time horizon was considered by various household segments. This information will be further investigated in a subsequent quantitative analysis (problem no.2).

The second research problem which we will cover is to quantitatively analyse how effective was the thermal insulation with respect to energy use in the insulated flats. We would try to examine, depending on data availability, whether the effect of insulation has backfired (Gillingham et al. 2014) thanks to lesser incentives to save energy to heat their homes after the marginal price of energy service was lowered so the comfort they enjoy will cost them less. Probably the dwellers in insulated flats spend similarly and thus demand for higher heat comfort and hence enjoy better environment for living in. This effect is called direct rebound effect (Gillingham et al. 2014).

Hypotheses The main barrier for realisation of energy efficient investment in cooperative owned flats in the apartment buildings is a lack of financial resources, undervalued energy savings, short-term orientation, and high transaction costs related to finding a mutually optimal solution. Providing subsidy of investment (capital) costs is not sufficient incentive to motivate the dwelling unit owners to invest in energy efficiency in jointly owned apartment building. Energy savings in a flat after thermal insulation of the building vary across dwelling units. Investment in insulation is highly related to the energy savings. On the other hand the government subsidy is not related with energy savings.

Methodology Pre-survey (literature review, one-on-one interviews with heads of associations of unit owners and dwelling unit owners); Semi-structured interview with heads of associations of unit owners; Structured interviews with dwelling unit owners by using questionnaire and Statistical and econometric analysis

Outline

1. Introduction
2. Literature review (Energy efficiency paradox, focusing on decision making process in cooperative owned dwellings; Rebound effect of insulation)
3. Decision – making of associations of unit owners
4. Description of data, sampling strategy and the survey
5. Theoretic and econometric model of effectiveness of energy saving of flat heating in thermal insulated apartment buildings
6. Data Analysis
7. Conclusion

Core bibliography

1. Gardner, G. T., Stern, P. C. (2009). The short list: Most effective actions U.S. households can take to limit climate change. Environment, 50(5): 12–25.
2. Gerarden, T., Newell, R. G., Stavins, R. N. (2015). Assessing the Energy-Efficiency Gap. Working paper, Harvard University.
3. Gillingham, K., Newell, R. G., Palmer, K. (2009). Energy Efficiency Economics and Policy. NBER Working Paper No. 15031.
4. Gillingham, K., Rapson, D., Wagner, G. (2014). The Rebound Effect and Energy Efficiency Policy. Working Papers 2014.107, Fondazione Eni Enrico Mattei.
5. Jaffe, A. B., Stavins, R. N. (1994). The energy-efficiency gap. What does it mean? Energy Policy, 22(10): 804-810.

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ACRONYMS

AECH	Annual Energy Consumption on Heating
CZ	Czech Republic
CZK	Czech Koruna
EE	Energy Efficiency
EED	Energy Efficiency Directive
EU	European Union
EPBD	Energy Performance of Buildings Directive
FE	Fixed Effect
GHG	Green-House Gases
GJ	Giga Joule
HDD	Heating Degree Days
IROP	Integrated Regional Operational Programme
MFB	Multi-Family Apartment Buildings
NAECH	Normalized Annual Energy Consumption on Heating
NEEAP	National Energy Efficiency Action Plans
NGS	New Green for Savings
OLS	Ordinary Least Squares
PC	Plinth and Cellar Insulation
PJ	Petajoule
RE	Random Effect
SECA	Specific Energy Consumption per Year

SFH Single Family House

SVJ Associations of Unit Owners (acronym according to the original name in Czech “Společenství vlastníků jednotek”)

TBO Thermal Regulation, Balconies Reconstructions and Others

WRW Walls and Roof Insulation & Window Replacement

1 INTRODUCTION

As a result of earlier housing developments in the Czech Republic, many residential buildings remain, by today‘s standards, obsolete and energy-inefficient. Due to the legacy of lower standards previously applied in the construction industry, much of the housing stock is deemed unacceptable for modern living. The mainly prefabricated materials that were used for residential buildings between the 1960s and 1980s are now outdated. Moreover, these buildings are not fully insulated and in need of the repair. Large investments are required for refurbishment and insulation of these buildings in order for them to comply with current living and energy efficiency standards. Energy-inefficient buildings use extensive amounts of energy to keep them heated, causing energy consumption to be at a largely unsustainable level.

Nowadays, energy issues are at the top of the worldwide policy agenda, as the emission of green-house gases (GHG) to the atmosphere and their concentration therein reach ever-higher levels. It has been agreed that some basic steps are essential in order to restrict further increase in GHG emissions. As a first step towards much needed changes in this area, the “Kyoto Protocol”[1] global treaty was ratified in 1997. More recently, a fundamental agreement was reached at the COP 21[2] in Paris in December 2015.

As a response to these developments in environmental politics, several regulations focusing on energy efficiency in residential buildings were issued by the European Union (EU). Firstly, the EU introduced the Energy Performance of Buildings Directive (EPBD). This Directive requires EU members to meet the minimum energy performance specifications when building new houses, as well as when upgrading existing buildings and replacing some parts of the structure (such as the heating system, walls, roofs, windows etc.). This Directive also requires that the members introduce national financial measures that would enhance energy efficiency in the buildings.[3]

The Energy Efficiency Directive (EED) introduced in 2012 legally binds the members’ governments to develop and implement renovation strategies that should then be

[1] Kyoto Protocol is the international treaty between states that commits participants to reduce the green-house gases emissions after consideration of global warming existence caused by CO_2 emissions.
[2] COP 21 is the United Nations Conference on Climate Change.
[3] Source: ec.europa.eu - Cost-Effective Climate Protection in the EU Building Stock of the New EU Member States Beyond the EU Energy Performance of Buildings Directive.

incorporated into the National Energy Efficiency Action Plans (NEEAP).[4] The Czech Republic, as a member of the EU, implemented this Directive's requirements into its national legislation by the Act No 406/2000 Sb. Subsequently the Czech government released NEEAP of the Czech Republic in 2014.

The climate-energy targets introduced by the 2020 Climate & Energy Package (European Commission) were defined as the 20-20-20 targets (Decision No 406/2009/EC, Directive 2009/28/EC and Directive 2012/27/EU). These goals were specified as the following: (i) to decrease the GHG emissions by 20 % in relation to the GHG emissions levels in 1990, (ii) to increase the share of renewable energy within the total energy consumption in the EU by 20 %, and (iii) to increase energy efficiency by 20 % by 2020. In October 2014 the European Council updated these targets to 40-27-27, which should be reached by 2030. Those two EU policy commitments were integrated into the EU Roadmap for Moving to a Competitive Low-Carbon Economy in 2050. In this document it is proposed that by 2050 the level of domestic emissions should be reduced by 80 % of the level of emissions in 1990. The adopted Strategic Energy Technology (SET) Plan promotes research and innovation. It also creates a technology platform for the EU's conversion to a low-carbon energy system.

This thesis attempts to contribute to the understanding of how the problem of low energy efficiency can be tackled in a better way in the Czech Republic. Specifically, we wish to contribute to empirical literature by exploring and analysing the energy saving potential in multi-family apartment buildings in the Czech Republic. In this paper, we attempt to analyse the effects of retrofitting apartment buildings which have more than eight dwelling units.

Energy consumption in residential housing in the Czech Republic is not insignificant. It is about 30 % of the total energy consumption. Šafařík et al. (2013) conclude that the heating of single-family houses and multi-family buildings accounts for 60 % of the total energy consumption in the entire residential sector. Out of almost 4 million dwelling units, 54 % are in the multi-family apartment buildings, and only 34 % of these were insulated in some way. Although the rate of refurbishments in multi-family buildings is higher than in single-family houses (by 11.5 %), there is still a huge potential for energy savings. In fact, considering all dwellings, the energy saving

[4] NEEAP determines estimated energy consumption, planned energy efficiency measures and what enhancement EU member expects to attain.

potential is estimated to be 32 petajoules (PJ) per year by 2030 compared to energy consumption in 2011.

The main objective of this study is to analyse (i) how successful and effective the government funding of multi-family building renovations in the Czech Republic was, and (ii) how large this effect was in terms of energy consumption.

The supplementary goals of this research include (iii) what the main obstacles in the decision making processes of the owners of the dwelling units were, and (iv) whether there was any potential for free-riding due to energy efficiency grants.

Although our sample is relatively small, our econometric analysis provides interesting results. On average, the thermal projects in the multi-family apartment buildings led to a reduction in energy use for heating by 0.13 GJ per each m^2. In average, each million of investment reduced heat consumption by 297 GJ annually, which implies 176,299 CZK of financial savings each year or about 46 years of payoff (without discounting). Providing subsidy allowed SVJ to invest in much large insulation projects that were also more efficient. For the projects that received a subsidy, energy savings were 327.5 GJ per m^2 per year (23,744 CZK per million CZK of investment), while they are 283.69 GJ per m^2 (20,567 CZK per million CZK) for the projects without a subsidy.

The structure of this study is as follows: Chapter Two provides a literature review including a brief overview of the energy efficiency gap problem, which is also called the energy paradox, and the rebound effect. The multi-family apartment buildings market is described in the following chapter, paying special attention to the decision making process by the owners of dwelling units in apartment buildings. Chapter Four is divided into three parts. The first part describes data, the sampling strategy and the survey. Theoretical and econometric models that analyse the effectiveness of energy savings due to thermal insulation of the buildings are discussed in the second part of Chapter Four. The econometric analysis is presented in the last part of the same Chapter. The final chapter provides the conclusion together with some policy recommendations.

2 LITERATURE REVIEW

2.1 Energy efficiency gap

Allcott and Greenstone (2012) define the energy efficiency gap as the difference between the most cost-reducing level and the level that is in fact occurred. As they mentioned in their work, the *energy efficiency gap* is a complex of forces they called *investment inefficiencies*. It incorporates consumption of fossil fuels that brings e.g. negative externalities such as health harm or global warming and the forces that may lead to wrong decision about the undertaking of profitable investment.

According to Gerarden et al. (2015), despite the estimates and economic models of the energy-efficient technologies, decision makers are quite restrained and tend to underinvest in those technologies. They try to explain this *energy efficiency gap* by three possibilities. The first of them are *market failures* which could be caused mainly by lack and imperfect information as Jaffe and Stavins (1994) agree with. They also emphasise the *principal-agent problem*, which arises from the difficulties of informing the benefiting party about energy savings. In other words it means that the principal (landlord) and agents (tenants) can differ in the attitude to which action to take. Gillingham and Palmer (2013) complete the list of market failures by another three items so called *liquidity constraints* concerning the limited availability of financial means (e.g. because of credit rating that is difficult to tell the borrowers apart based on poor information), *learning by using* indicating that the sharing of knowledge gained by using the new energy-efficient technology will improve the initial decision making process to invest in these technologies (e.g. showing the real example of the technology already used may better convince the decision-makers) and finally *regulatory failures* that can be the consequence of wrong economic regulation such as the energy prices decreasing under the level of marginal costs resulting in diminished incentives to invest in energy efficiency. Such a regulation could lead to further widening of the energy efficiency gap. Gerarden et al. (2015) stress the importance of the *behaviour issues* in prediction making, such as predictions based on wrong or unverified assumptions further distorting the perceived energy efficiency gap. Those non-market behavioural failures may include the heterogeneity and inertia of consumers (the prospect theory), limited information processing (the theory of bounded rationality) or uncertainty about future energy prices and actual savings from energy efficiency investments. These behavioral barriers in the end-user's decision making with respect to energy consumption are among the factors leading to emergence of the energy efficiency gap. Consequently, policies that seek to improve energy efficiency usually attempt to influence one or more of these factors. In the latter, they are speaking about the *modelling flows* based on unobserved costs of adoption as well as the negligence of heterogeneity in benefits and cost of adoption between the people who are probably going to accept the energy-efficient technologies.

Jaffe and Stavins (1994) identify the suitability of government policy interventions as the main reason why to measure the energy efficiency gap. They claim it is necessary to know if the market failures removed by government interventions when the energy efficiency gap is in place, would improve total resource allocation or not. Since it would lead to resource allocation improvement it is good reason for introduction of such government policy. However, there could also be some market barriers which are not market failures. In such a case, the implementation of the government policy would not resolve the energy efficiency gap. They also state that market failures do not have to be necessarily related to energy paradox, but government intervention may still improve the situation if it deviates from the *social optimum* (e.g. because of environmental externalities).

Allcott and Greenstone (2012) propose the government policy for two cases of market failures such as *energy use externalities* and *investment inefficiencies* to obtain the *social optimum*. In the first case, the energy use externalities could be combated by imposing *Pigouvian taxes*[5] or *cap-and-trade programmes*[6]. In the second case, investment inefficiencies could be resolved by providing and clarifying all information needed for decision making process concerning undertaking of the investment. As a result it may lead to diminishing investment inefficiencies even though sometimes it may not be sufficient. Therefore, they propose further solution that might improve social welfare which could be for instance providing some government subsidy for energy efficiency. Arimura et al. (2011) remind the policymakers to research the past

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[5] Pigouvian taxes are taxes levied on companies that pollute the environment (so create the negative externalities) and considered as the best way how to adjust these externalities.

[6] Cap-and-trade programmes aim at reduction of given type of emissions providing a special profit in the mean of selling unused portion of limit to its peers (in other words this motivates them to reduce firms pollution as fast as possible).

policies and programmes to find the most effective one to preserve cost-effective energy savings.

2.2 Rebound effect

Gillingham and Palmer (2013) call attention to the other side of subsidy. The rebound effect can appear and so reduces the energy savings from the originally energy-efficient investment. Polimeni et al. (2008) refer to the Jevons' paradox as there is potentially higher usage of energy as we improve the energy efficiency. Gillingham et al. (2014) defines the rebound effect as the difference between real and predicted energy savings that did not take consumers responses into consideration. They also state that with the improvement of energy efficiency the cost of using energy goes down (the price differs) and so consumers' consumption is influenced both by income and substitution effect. Consumers will adjust their consumption by so referred several movements. First, they will tend towards more energy-efficient product which is less expensive alternative now. Second, as the price of energy consumption decreases consumers can purchase more and raise their consumption of this more energy-efficient product. Finally the consumers start consuming other products as their purchasing power increased. Gillingham and Palmer (2013) discussed the problem of underestimation of the magnitude of the energy-efficiency gap as they do not take into account the difference between the energy service before and after the energy efficiency investment. Hence, again the rebound effect arises. Thus, they try to point out the fact that if we do not consider for the rebound effect, the estimates of *cost-effective energy savings* will be probably biased upwards.

2.3 Free-rider problem

There is also one more issue the policy-makers have to deal with known as a *free-rider problem* that can arise from introduction of the government subsidy. Nauleau (2014) claims that omitting the free-riding can lead to magnified effect of subsidy on energy savings (without subsidy there will still be people - here known as free-riders - who would undergo the purchase and implementation of new energy-efficient technology). As a result, such a policy could be considered effective even though it could have minimal effect. Other researchers such as Attali and Geller (2005) have set up a concept of *free-drivers* relating to increasing awareness of energy-efficient technology by reason of the subsidy even though they do not have to leverage it. To the concern of thermal insulation Alberini et al. (2013) have found out the heating system replacement seems to incline more to experience free-rider problem than for example window replacement.

2.4 Collective vs. individual energy choices

The most researches on residential EE investments are limited to households who live in single-family houses (SFH). This is in part because SFH tend to use more energy than dwelling units in multi-family buildings (MFB), and in part because SFH homeowners do not have to negotiate or compromise with others when making EE decisions. However, some 25 % of the population in Europe lives in MFB where decisions about installing insulation and heating and cooling equipment must be made collectively.

To reveal the behaviour of decision-makers in each section of housing we need to go through different barriers of EE decisions, Hynek et al. (2012) reveal that the drivers of the investment decisions in thermal retrofitting are very difficult to understand in MFBs (represented by SVJ in CZ). People in MFBs face the problem of *split incentive* that influences their decision making. It is considered to be a market failure and we have to reveal how MFBs are funded and how they operate. *Split incentive* appears mainly when people believe the benefits of transaction realized by retrofitting MFB go to a third party which does not pay the transaction costs.

Our research of decision-making process of SVJ will use a mix of qualitative and quantitative approaches to identify the hurdles in collective-decisions and the way to overcome them. Hurdles may be legal, administrative, financial, and subjective assessment of costs and benefits from the upgrades, etc. Providing the results and analysis helps to fill the research gap in this topic.

3 MULTI-FAMILY APARTMENT BUILDINGS AND COLLECTIVE DECISIONS

This research tries to analyse the decision-making process of the associations of unit owners on undergoing the thermal insulation at their homes. At first, we will introduce the associations of unit owners, their institutional bodies, and discuss in particular the decision-making process and its possible obstacles. The last it is the survey and the results it brings.

3.1 Association of unit owners

The housing stock of the Czech Republic is divided along the homeowners to state, municipal, commercial, private or jointly-owned apartment buildings. In the apartment buildings with five and more dwellings owned by more than three people there is an obligation of the Czech law imposing the establishment of the association[7] of the people who are the owners of an apartment in this building (or more flats as well) called a*ssociation of unit owners* (SVJ)[8] but this SVJ does not arise from the law but it is established by registration into the public list. Each of those people owns part of the whole building as the share of square metres given by their flat area to the total floor area of the apartment building (= building). This share is transferred into votes which are then considered when making decisions. With increasing number of the owners in one building the problem with decision-making arises.

According to Section 1200-1 of Act No 89/2012 Sb. the formation of SVJ is officially made by Articles approval even though sometimes it could have been already founded by reconciliation of the division rights in lands and buildings through the agreement in contract of construction.[9]

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[7] Source: http://www.epravo.cz/top/clanky/spolecenstvi-vlastniku-ve-staronovem-kabate-94543.html.

[8] SVJ is term used to facility management legally divided into independent housing units and common places (by Act No 72/1994 Sb. or by Act No 89/2012 Sb.).

[9] The Czech Civil Code Articles requirements (Section 1200-2 of Act No 89/2012 Sb..) are the following:

i) Name of SVJ and house identification the SVJ is related with;
ii) Registered office (located in the building the SVJ is established for);
iii) The rights and duties of housing unit owners and their exercise;
iv) Body implementation, definition of their competences, number of members, term of office and practice for the convening, negotiations and deliberations of the committee;
v) Defining of the first members of governing body;
vi) Common rules for facility management and usage of common places;
vii) Budgetary planning of SVJ, setting of contributions to facility management and service expenditures.

Although governing body of the SVJ is usually *Committee* sometimes we can meet with SVJ where the governing body is only *Chairman of the associations of unit owners* (Section 1205-1 of Act No 89/2012 Sb.). According to the lately introduced version of the Czech law, it is not necessary the member of governing body has to be a member of SVJ (it can be also a "stranger").

The highest authority of SVJ is *Assembly of Committee* composed of all dwelling unit owners. Number of votes of each owner corresponds to the share of the owned floor area. The quorum of the Assembly usually consists of the majority of all possible votes. However, the Assembly will be quorate if and only if the majority of its owners are present. According to Section 1206-1 of Act No 89/2012 Sb. about the Assembly, to approve and adopt the decision of the Assembly the Czech law determines the majority of all present owners (or absolute majority of all present when the law requires it or prescribed quorum in Articles which is higher). The meeting is conveyed by governing body at least once a year by the law announcing the main concern of the meeting in advance.

3.2 Decision-making process in SVJ

Firstly, there has to be an incentive to start the discussion about the realization of thermal insulation. Both the governing body and the Assembly can propose it to start the procedure of decision. Specifically, according to Section 1208 of Act No 89/2012 Sb., the competences of the Assembly include inter alia g*ranting prior consent to acquire, dispose or burden of immovable assets or other use of them, and decide on a Loan Agreement, including total amount of a loan and terms of a loan.*[10] According to Section 1206, Act No 89/2012 Sb. to decide about changing common places of the building, including its renovation or thermal insulation, at least one half of votes of all present owners have to agree and the Assembly has to be quorate, that is, at least one

[10] According to Section 1208, Act No 89/2012 Sb., Assembly competencies include: (i) changing of the Articles; (ii) changing the reconciliation about the division of unit ownership rights in lands and buildings; (iii) election and dismissal of members of elected authorities and decision-making about their remuneration; (iv) the accounts approval, settlement of operating results and the reports of the facility management and total amount of members' contributions into the repair fund for the coming period and decision making about the unused capital; (v) confirmation of services and amount of deposit needed for covering the service expenses and division of contribution according to owned share in the apartment building; (vi) decision-making process concerning: (a) membership of SVJ in legal entity, (b) change of purpose of the building or dwelling, (c) change of flat floor area, (d) connection or division of housing units, (e) change of share of common places, (f) change of determination of common places serving to exclusive usage of flat owner, (g) repair or construction adjustment of common places if costs outweigh the amount given by implementing legislation or Articles; (vii) granting prior consent to: (a) acquire, dispose or burden of immovable assets or other use of them, (b) acquire, dispose or burden of movable assets whose value exceeds the amount given by implementing legislation or other use of them (Articles may secure an opt-out), (c) conclusion of a Loan Agreement of SVJ including total amount of a loan and terms of a loan, (d) conclusion of a Mortgage to dwelling unit if the owner gave a written approval of this conclusion, (e) identify the person who should ensure some of the responsibilities of management facility and make decisions about its change, (f) decide in matters defined by Articles or other matters the Assembly reserved.

half of total votes represented by owners has to be present by the law but depends on Articles defined quorum if it is higher. In the case of changing function of the building or the part of the building or adding the superstructure, it is necessary according to Section 1208 number vi) letter g) of Act No 89/2012 Sb. to sign the contract for construction by all owners (it could be construction of attic or new roof). There is also another opportunity how to decide about the insulation without convening the Assembly. Section 1214 of Act No 89/2012 Sb. introduces the correspondence decision making called per rollam or decision taken outside meeting (but SVJ has to comprise this option into the Articles) and the majority of total number of votes has to agree. By the old law (Act No 72/1994 Sb.) there was defined the necessary majority forming firstly 100% of all owners and then it was reduced into at least three quarters of total number of owners' votes which is now possible to be changed in the Articles by the new law (Act No 89/2012 Sb.) to the current version of a law (at least one half) or to the new optional quorum (e.g. two thirds).

3.3 Energy consumption by multi-family apartment buildings

Šafařík et al. (2013) conclude the energy consumption of all residential buildings in Czech Republic is about 30 % of total energy consumption of CZ. Heating of all residential buildings (including both SFH and MFB) uses 60 % of total energy supplied to all residential buildings. Population and housing census in 2011 calculated almost 4 million of dwelling units in CZ with 46 % of single-family houses (SFH) and 54 % of multi-family apartment buildings (MFB). Renovation was done only in 23 % of stock of dwellings in CZ. 12.5 % of single family houses completed renovation by 2011 and 34 % of multi-family buildings did so too. The detailed description of shares of retrofitted and non-retrofitted SFH and MFB in CZ in 2011 is displayed in Table 3.1. Regarding the trends of renovations and maintenance of funding programmes in the future there is a large energy saving potential. Annual reduction in energy consumption by 2030 compared to 2011 (including all dwelling units of SFH and MFB) is estimated to the absolute value of 32 PJ. Currently MFB outside Prague can ask for the endowment of Integrated Regional Operational Programme (IROP) and MFB inside the capital can apply for the subsidy from New Green for Savings Programme (NGS) which helps the investors to fund the renovations related with insulations. Table 3.2 depicts proposed changes in shares of renovations by 2020.

89%			Non - retrofitted FH	1 600 000 d.u.
78%			Non - retrofitted AB (not prefab)	740 000 d.u.
56%			Non - retrofitted AB (prefabs)	670 000 d.u.
11%			Retrofitted FH	200 000 d.u.
22%			Retrofitted AB (not prefab)	210 000 d.u.
44%			Retrofitted AB (prefab)	530 000 d.u.

Table 3.1 - Share of retrofitted and non-retrofitted dwelling units in 2012

Source: tzb-info.cz

78%			Non - retrofitted FH	1 400 000 d.u.
62%			Non - retrofitted AB (not prefab)	600 000 d.u.
20%			Non - retrofitted AB (prefabs)	240 000 d.u.
22%			Retrofitted FH	395 000 d.u.
38%			Retrofitted AB (not prefab)	370 000 d.u.
80%			Retrofitted AB (prefab)	1 200 000 d.u.

Table 3.2 - Share of retrofitted and non retrofitted dwelling units proposed by 2020

Source: tzb-info.cz

3.4 Data collection and sample description

As a source of data for the SVJ energy choice survey serve the responses to questionnaire (see Appendix C) created on baselines of our literature review.

The questionnaire was provided online on the web and was accessible via a web-link sent to SVJ members by email and posted on portal websites, like portalsvj.cz and portalobydleni.cz, that are regularly visited by apartment owners and other people interested in the issue of insulation of buildings in relation with energy efficiency, energy savings and environmental improvement. The questionnaire allows us to depict the ideas behind their decisions and to summarize the effects of insulation provided by the feedback of respondents from MFB.

Among our respondents to online questionnaire there are 59 % males, with average age ranging between 41 – 50 years and almost three quarters of them are employed. Females form 41 % of our respondents with average age ranging between 41 – 50 years and almost two thirds of them are working (see Appendix A).

In total, 74 completed questionnaires were obtained and each questionnaire provides detailed information about housing performance of SVJ (representing multi-family apartment building). Out of all 74 valid observations certain kind of thermal insulation has been installed in 51 SVJ units in last 10 years that provides us relatively rich statistical source of information (treatment group). The remaining 23 SVJs have not insulated their building in last 10 years, and these observations represent the control group.

3.5 Analysis of SVJ's decision-making process on thermal insulation

The first part of our research explores the decision-making process of SVJ and their opinions towards Insulation and particular measures related with insulation. Figure 3.1 displays the main reasons for not implementing the insulation. There are 22 % of responding units who were against the insulation. No proposal to insulate MFB has been raised in 39 % of responses. *Others* category includes in total 9 units: 3 respondents stating that they are going to insulate in close future, another 3 who could not insulate their homes since their buildings are in protected heritage zones (even though they would like to, as stated in the survey), and the remaining 3 claimed that they are in financial problems and cannot afford such an expensive investment.

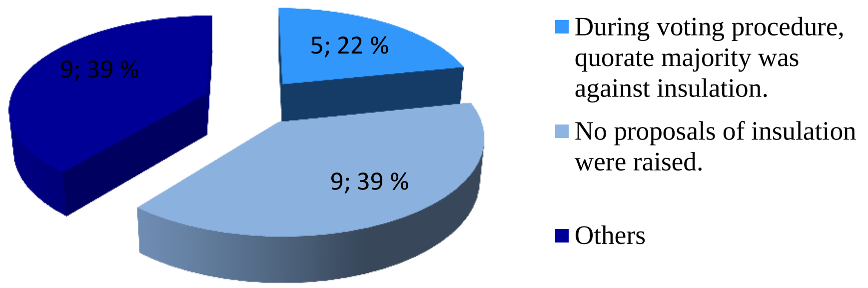

Figure 3.1 - Reasons for decision against insulation

Source: Author's computation using the data from the dataset.

There is no detailed information about not raising such proposal, one could only hypothesize about market failure effects, such as missing information or not well informed people or not sufficient conviction that insulation leads to defensible satisfactory levels of energy savings and so we should propose better promotion and presentations of justifiable outcomes to public. That could also encourage others who voted against or who are not persuaded that it is financially profitable at all.

Among our respondents, there are two main obstacles for not performing the thermal insulation of the buildings: large debts (48 %) and problems associated with insulation works (30 %).

Debts	11
Problems associated with insulation works	7
None	5

Table 3.3 - Insulation drawbacks

Source: Author's computation using the data from the dataset.

Debts issues stand for the problem of insulation project funding. People usually do not have enough financial means in SVJ's repair fund and so they have to take a loan to obtain needed amount of money. *Problems associated with insulation works* are related to the inconveniences induced by the building works such as air and noise pollution and the possible delays in deadlines. In some cases people do not trust the firm to do the work correctly and so it can lead to undesired effects such as detection of mould or condensation of humidity inside the building. Almost one fourth of buildings that implemented insulation confirmed that after insulation they faced increased humidity. There was not any problem with moulds at all (only 4 % of those who did the reconstruction detected mould).

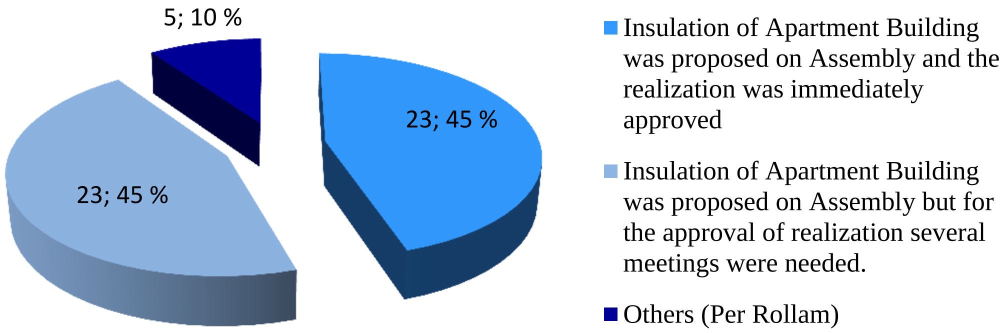

Figure 3.2 - Process of decision-making whether to insulate

Source: Author's computation using the data from the dataset.

Now we focus on the SVJ that implemented the insulation. Procedure of making decisions has been already described in decision-making process about the thermal insulation and other repairs. We collected the responses showed in Figure 3.2 above where the first value signs the number of votes and the second shows the proportion to total votes for this question.

Among the analysed units, the decision about insulation of apartment building was either approved immediately after proposed to Assembly (45 %) or the approval was made after several meetings (45 %). Only in 10 %, the decision was approved through other form, in particular by per rollam voting. The reason, why people need to meet more times than once, could be given by the obstacles people face in decision-making process (e.g. financing of the insulation project).

3.5.1 The funding and subsidy connection to insulation

Regarding the funding arrangement, the preferred funding differs between the units that have already installed the insulation and the units that are not insulated yet.

Funding Arrangements	Insulated (N = 51)	Non-insulated (N = 23)
Repair Fund	19.6 %	34.8 %
Subsidy + Repair Fund	1.9 %	34.8 %
Loan	15.7 %	0 %
Subsidy + Loan	9.8 %	8.7 %
Repair Fund + Loan	29.4 %	4.3 %
Repair Fund + Loan + Subsidy	19.6 %	17.4 %
Subsidy	3.9 %	0 %

Table 3.4 - Funding arrangements

Source: Author's computation using the data from the dataset.

The respondents from non-insulated buildings are afraid of debt issues (related to loans) and so they rather vote for investment using financial means from their repair funds. On the other hand the people from insulated buildings used more often the repair funds in combination with loans. Their behaviour seems more rational as they are probably well-informed and may know that large investment allows them to afford more efficient and complex insulation measures compared to the measures leading to small or moderate savings that cost less and can be easily covered from their repair funds. Our observation is in line with other literature referring to information asymmetry (see literature review).

Providing subsidy appeared as non-sufficient incentive to motivate SVJ to invest in energy efficient technologies like thermal insulation. Our survey shows that 41 % of all SVJs (N = 21) who invested in insulation also demanded for a government subsidy and 81 % of those applicants (N = 17) were also successful to receive it.

Only 3 out of 17 respondents who received the grant (about one fifth) said that without receiving the subsidy they would not decide to invest in the thermal insulation. In other words more than 80 % of investors in thermal insulation would decide to invest anyway that may indicate on the free-riding behaviour. The setbacks connected to application for subsidy like complicated administration, expensive handouts preparation or not available grant application could be the reason why some SVJs did not apply for it. However, without the subsidy the investors might decide in less expensive and less efficient insulation project. Moreover, subsidy programmes increase general awareness of insulation.

3.5.2 Satisfaction with insulation and further improvements

The respondents involved in our survey have been mainly satisfied (80 %) with the results of insulation. Insulation brings many positive effects. The major positive effect is mainly associated with energy savings (related to financial savings). Most of the investors - 90 % - are convinced the investment in thermal insulation will pay off and about 86 % of them think it will increase market price of their flat. They feel the cold coming from the walls and the floors has got better (74 %, and 24 %, respectively). In general, those who invested in thermal insulation perceive thermal conditions inside the building have improved (during hot summers inside temperatures are lower than before insulation). In some cases, the investors perceived undesirable effects due to thermal insulation like mould (4 % of all insulated buildings in our survey) or condensation of humidity (24 % of insulated buildings in our survey), however that might be a consequence of poorly or inappropriately installed insulation.

Respondents are generally satisfied with insulation performance, but some of them can still consider energy saving potential provided by further measures that could even improve their well-being. The respondents who insulated their buildings have then mainly called for instalment of thermo-meters to set up the thermal regulation more effective and hence to avoid wasting energy (35 %).[11] Another most often stated request called for detaching the apartment building from distance heating system and to connect their house to other less expensive heating source. Next, all who have not implemented wall and roof insulation yet think they should do so (also demonstrated by the successive econometric analysis).

[11] Source: http://www.subregulace.cz/co-je-subregulace-tepla-a-proc-je-dobre-ji-mit-v-bytovem-dome/.

4 ANALYSIS OF INSULATION EFFECT ON ENERGY CONSUMPTION

4.1 Data

4.1.1 Data collection and sample description

Our research aimed at apartment buildings which have already been insulated in the past 10 years, which could provide information on energy consumption for at least three years before and three years after insulation took place. It was necessary to obtain energy consumption for heating at least three years before and three yeasr after the insulation was installed as we want to observe the effect of insulation on energy savings. Other key variables included are heated floor area (square metres), total financial investment and subsidy, refurbishment actually realized, and the year the installation of thermal insulation was finished.

Data used in this econometric analysis were collected through three main sources of survey– email questionnaire, face-to face interviews with heads of SVJ and facility management companies' documentation for insulated SVJs. The first, online approach showed to be inefficient since the response rate was very low (8 out of 200 sent emails[12] were responded to). The rest of the survey was conducted in two Czech cities, Prague and Pilsen that were easily accessible areas for us. The survey was accomplished during January and February 2016. Meetings with heads of SVJ were arranged by phone calls. Phone numbers were collected either by browsing of given member of SVJ (ARES)[13] or obtained from facility management companies. Finally, the third and the most effective option for data collection relied on communication with facility management companies. Each of those companies[14] provided the documentation for at least three MFB. Every time, heads of SVJ had to be contacted to approve the supply of information. All of these companies were compliant to provide at least phone numbers to some SVJ members (usually 2-3 contacts) despite the annual breakdown deadline.

[12] Email addresses were obtained through available web-sites of SVJ searched by internet browser.
[13] ARES is the administrative business register.
[14] Companies involved in facility management that were queried in Pilsen and Prague - searched at firmy.cz and nemovitosti-sprava.cz.

Altogether the data we have obtained from each source forms 18 %, 27 % and 55 %, consecutively.

Other information about the buildings characteristics like number of dwellings, number of floors or the altitude were searched on the internet mainly on the websites regiony.kurzy.cz, tzb.info.cz and cbpmr.cz.

4.1.2 Variable coding

The research is focused mainly on the examination of the influence of thermal insulation, investment and government subsidy on energy consumption. Thus, these are the main aspects we were interested in examinig. In our data collection we were aimed at several points. Firstly, we have to deal with the problem of energy consumption gathering and its interpretation. Secondly, we have to describe the investment and government subsidy variable. Finally, we have to cope with insulation and its types and possible correlation. After that, we set up all needed explanatory variables to our model.

4.1.2.1 Energy consumption for heating

Altogether, we succeeded to gather up energy consumption data for 45 insulated apartment buildings over 6 year period including 3 years before and 3 years after the insulation.

The energy consumption was collected usually from individual accounting of energy uses for heating in which the data for whole apartment building are available. Usually it is given in the annual sum of gigajoules used for heating (sometimes kilowatt-hours are used instead). Sometimes SVJ were keeping own records over the decades with the energy consumption for heating.

We define *annual energy consumption on heating* (AECH) as actual energy consumption recorded over the calendar year starting on 1th January and ending on 31th December of each respective year and is expressed in gigajoules (GJ).

In order to control for different weather conditions every year we normalize energy consumption by the *heating degree days* (HDD) that are for each year given by the following formula:

$$HDD = d(t_i - t_o) \tag{4.1}$$

where *d* stands for number of days the heating was working, t_{ir} represents the mean indoor temperature and t_{or} represents the mean outdoor temperature of the r-th day in the given year. Total number of HDD measures the difference of outdoor and indoor temperature multiplied by heating days (counting only the days when outside temperature decreases below 13 °C).

There are two different measures of HDD: climate and meteorological. The first one uses the long-term average of temperatures (e.g. fifty-years average of 1901 to 1950), while the second one measures the exact number of HDD in the given year. The latter approach is mostly used for controlling climatic conditions when the effect of newly implemented technologies on energy use is analysed (Horáková et al., 2013).

To obtain good estimates of real energy savings, we thus convert AECH to *normalized annual energy consumption on heating* (NAECH), as follows:

$$NAECH = AECH \times \frac{D_N^{\circ}}{D_A^{\circ}} \qquad (4.2)$$

where D_N° stands for the long term average number of HDD in the given place over the year and D_A° is actual number of HDD in the considered heating season.

To obtain the approximate value of HDD for the places where the buildings from our sample are located, we have several options to follow. The first and the most appropriate one is the usage of the energy audit[15] information, where HDD are recorded for previous three years regarding the realization of insulation. However, since it was not obligation to prepare this audit before the insulation for all of SVJ who wanted to do this reconstruction there are many of the apartment buildings where this information was unavailable. Moreover there are HDD missing in the energy audit for the years after the insulation since it is only report about the previous state of the building and proposed changes. Therefore, the second possibility is usage of the calculation model available on *tzb-info.cz* which collected HDD for more than 30 Czech cities over past 10 years. We can take the closest substitute of the measured place and convert data in our observed place by this HDD for this substitute since we assume that the weather conditions and the locations (situations) of those two places are comparable (or the deviation would be minimal). However, since the data in this calculation model are

[15] Source: http://www.aea.cz/energeticky-audit of the overview of energy audit and the conditions when energy audit is necessary to be made.

available only for past 10 years (in some places even less) we have data only till 2005 or 2006. Therefore, if we meet with the observation of the building insulated earlier than 2008 we will be missing the HDD for the years before 2005 since we examine 3 years before the implementation of the insulation. Hence, the third option is the source of those HDD on mpo-efekt.cz websites where are several publications of climatological data with HDD measured monthly and for heating seasons starting in September of one year and ending in August next year. So we just need to recalculate them into correct time period (for our data starting on the 1th of January and ending on the 31th of December of the same year).

4.1.2.2 Thermal insulation

Insulation is represented by eight possible options coded as dummies. These options include: wall insulation, roof insulation, window replacement, plinth insulation, balcony reconstruction, cellar insulation, thermal insulation and other reconstruction that stands for smaller adjustments (33 % cases). Among all of these options, walls and roofs were repaired most often (in 88 % and 88 % cases, respectively) followed by windows replacement (75 % of cases), while reconstruction of balconies and cellars were performed least often (26 % and 13 % of buildings, respectively); Thermal regulation was performed in 53 % of insulated apartment buildings (see Figure 4.1).

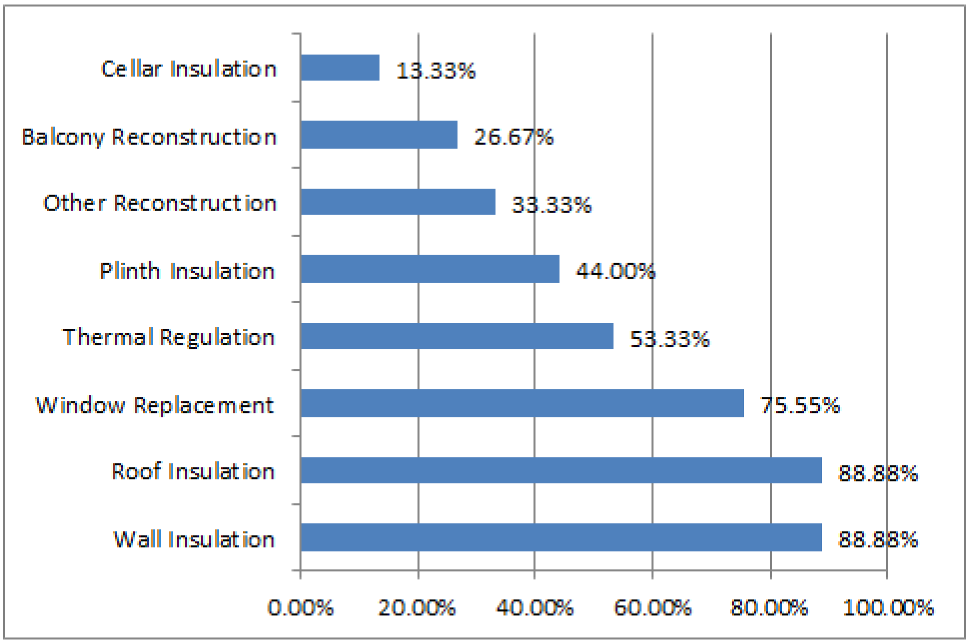

Figure 4.1 - Frequency of specific insulation measures, in % (N = 45)

Source: Author's computation using the data from the dataset.

As there is high frequency of some of the eight reconstruction steps, we should test for correlation between the individual dummies choosing *Pearson correlation*[16] that should be used in the case of testing correlation between 2 binary variables. To realize whether there is a correlation we procure the correlation process.

	Walls	Roofs	Winds	Plinths	Balcs	Cellars	Others	ThrReg
Walls	1.000							
Roofs	0.775	1.000						
Winds	0.825	0.778	1.000					
Plinths	0.543	0.490	0.520	1.000				
Balcs	0.438	0.372	0.503	0.340	1.000			
Cellars	0.209	0.119	0.159	0.500	0.026	1.000		
Others	0.260	0.440	0.266	-0.023	0.087	0.119	1.000	
ThrReg	0.623	0.421	0.566	0.221	0.207	0.342	0.404	1.000

Table 4.1 - Correlation between dummies for reconstruction

Source: Author's computation using the data from the dataset.

Table 4.1 provides the correlation coefficient matrix of all binary variables describing reconstruction made. Wall insulation, roof insulation and window replacement exhibit high correlation coefficients exceeding even the value of 0.75. Cellars and plinths correlation is also increased (the value of 0.5). Also the correlation between thermal regulation and wall, roof insulation and window replacement is raised. High correlation between dummies may cause problem while put together into model separately. Creation of the new variables may help to avoid this problem. We create *WRW*[17], *PC*[18] and *TBO*[19] and partially resolving the problem of correlation between particular parts of reconstruction.

4.1.2.3 Determinants of heating demand

The buildings areas are usually diverse and so to compare the buildings with each other it is necessary to either relate consumption to the total flat area or volume measures (as normalised dependent variable) or to control for their effect (as predictors). In our case the square meter seems to be accurate as we need to compare energy consumption

[16] Pearson correlation is convenient measure of the relationship between 2 binary variables giving the values ranging between -1 and 1. Positive value of this correlation corresponds to positive relationship between variables and otherwise. For absolute values above 0.75, we say variables are highly correlated.
[17] WRW is equal to the sum of individual dummies (wall insulation, roof insulation and window insulation).
[18] PC is equal to the sum of individual dummies (plinth and cellar insulation).
[19] TBO is equal to the sum of individual dummies (thermal and balcony insulation with the other measures).

between SVJ with different floor area related to heating. We express NAECH per floor area that is specific energy consumption per year (*SECA*).

4.1.2.3.1 Project variables

Dummy variable *PROJECT* equals to 1 for the years when the insulation was applied and 0 otherwise. This helps us to distinguish the effect of realization of insulation on energy savings.

SubsidyD is the dummy variable equal to one if SVJ received a grant from a government programme.

There are mainly two types of energy programmes for that a subsidy was provided. Not refundable subsidy is provided by Green for Savings Programme (and New Green for Savings Programme) for which the exact amount is available in majority cases. *SubsidyCZK6* is a continuous variable that just measures the total sum of financial means obtained from this source of funding, expressed in million CZK.

However, funding from so called Panel Programme (and New Panel Programme) is provided in a form of lower interest rates when the SVJ takes a loan to fund their building reconstruction. In order to control for the effect of various programmes, we define another dummy variable *SubsidyIR* that indicates the SVJ who received a support but its amount is not available.

Investment is the total sum of the financial means used for realization of all the counted steps of reconstruction (here represented by eight dummies), tax included. Investment variable is measured in CZK and is expressed in million CZK (*Inv6*).

4.1.2.4 Other explanatory variables

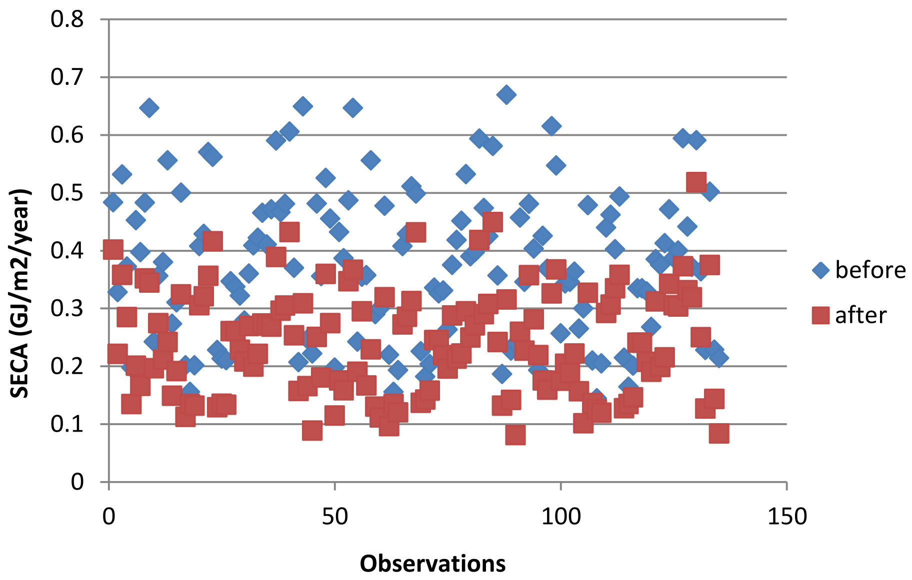

Figure 4.2 - Energy consumption before and after insulation

Source: Author's computation using the data from the dataset.

The time variable *YEAR* gets integer values between 1 and 6 and describes three years before (1, 2, 3) and three years after (4, 5, 6) the insulation was installed. Figure 4.2 above depicts the values the energy consumption had before and after the insulation in our dataset in relation to square meter.

In order to control for autonomous technological progress, we introduce two dummies that are defined by the year when the thermal insulation was implemented. Two dummies *Realization11* and *Realization09* equals to 1 when the insulation was implemented after 2011, or before 2009, respectively.

To test the trend of people learning and the possible consecutive shrinkage of their energy savings we introduce the variable *Learning* being 0 for the years before insulation and having values 1, 2, 3, consecutively after insulation was implemented. We will also test learning between consecutive years. Thus, we generate variable *Learning2* equal to 1 in the second year after insulation (t=5) and 0 otherwise and variable *Learning3* equal to 1 in the third year after insulation (t=6) and 0 otherwise.

Below is the Table 4.2 with descriptive statistics of our dataset.

Variable	Obs	Mean	Std. Dev.	Min	Max
DUOA	270	23	13.01129	1	45
YEAR	270	3.5	1.710997	1	6
EndYear	45	2010	1.712107	2006	2012
SECA	270	0.308968	0.130606	.0810141	.6691222
PROJECT	45	1	0	1	1
Realization11	45	0.244445	0.434613	0	1
Realization09	45	0.266667	0.447214	0	1
Inv6	45	8.188175	6.067268	.338563	25
SubsidyD	45	0.577778	0.499949	0	1
SubsidyCZK6	45	2.875959	2.871255	.306000	11
SubsidyIR	45	0.333333	0.476731	0	1
WRW	45	2.533	0.756787	1	3
TBO	45	1.133333	0.842075	0	3
PC	45	0.577777	0.722649	0	2
Walls	45	0.888888	0.317821	0	1
Roofs	45	0.888888	0.317821	0	1
Winds	45	0.755555	0.434613	0	1
Plinths	45	0.444444	0.502519	0	1
Balcs	45	0.266666	0.447214	0	1
Cellars	45	0.133333	0.343776	0	1
Others	45	0.333333	0.476731	0	1
ThrReg	45	0.533333	0.504525	0	1
AltitudeHDD	45	361.6067	48.539	287	561
AltitudeDUOA	45	351.9222	56.96896	230.8	589.8
NumberFloors	45	8.111111	2.257303	4	12
NumberFlats	45	58.02222	39.21373	9	180
FloorArea	45	3627.71	2611.845	549.8	11498.25

Table 4.2 - Descriptive statistics

Source: Author’s computation using the data from the dataset.

4.2 Methodology

As we observed an energy consumption of the 45 different apartment buildings (the *cross-sectional* elements) over the six year time period (*time dimension*) we are in favour of using *panel data* analysis. *Panel data* allows exploring the effect of treatment, i.e. the implementation of a new energy saving technology, controlling for the effect of other explanatory variables on energy consumption at the same time thanks to the consecutive observations for each individual unit.

We know there are many of the characteristics that are not observed in our econometric models known as *unobserved effects* (for instance the location, composition of the owners living in the building, their age, education, marital status, their financial situation and many others that could be correlated with explanatory variables in the model). Controlling for these effects, *random effects* (RE) or *fixed effects* (FE) can be used.

Theoretic panel data model to be estimated is given by the following equation:

$$y_{it} = \alpha_1 + \beta_1 x_{it1} + \beta_2 x_{it2} + \cdots + \beta_k x_{itk} + a_i + u_{it},\ t = 1,2 \ldots T \qquad (4.3)$$

where $i = 1,2, \ldots ,45$ denotes the apartment buildings (represented by SVJ) in the dataset according to their assigned ID numbers, t expresses time periods where $t = 1, 2\ and\ 3$ stands for time periods before insulation and $t = 4, 5\ and\ 6$ stands for time periods after the renovation, a_i captures an unobserved effect and u_{it} represents idiosyncratic error as referred to Appendix B. Intercept is excluded in case of fixed effects estimation.

Considering the assumptions for using either RE or FE (see Appendix B) if unobserved effect a_i is not correlated with each explanatory variable in the model, the equation (4.3) becomes a random effect model (Wooldridge, 2012) so following holds:

$$Cov(x_{itj}, a_i) = 0, \quad t = 1,2, \ldots , T; \quad j = 1,2, \ldots , k \qquad (4.4)$$

In line with our prior expectations, we assume that the factors included in the vector a_i (such as a location of the building or the level of owner‘s education) are correlated with some of the explanatory variables (such as the investment in renovation), hence, the conditions for using the RE model as a suitable estimator are not satisfied and the FE model should be rather estimated.

Using the FE method, as described in Appendix B, the final econometric model is as follows:

$$\ddot{y}_{it} = \beta_1 \ddot{x}_{it1} + \beta_2 \ddot{x}_{it2} + \cdots + \beta_k \ddot{x}_{itk} + \ddot{u}_{it}, \qquad t = 1,2, \ldots, T \tag{4.5}$$

Then can be estimated by general pooled OLS that is simple to be interpreted.

As we are using FE we assume that there are some individual factors (unique for each panel variable) which could have some impact on dependent or independent variable and that is why we need to control for it. Since the FE method eliminates the effect of time-invariant individual characteristics, such as flat area, geographical location, or considering reasonable time frame also education of decision-maker or household composition, the net effect of the explanatory variables on the explained variable can be determined. As the individual characteristics are specific for each panel variable, we suppose the error terms should not be correlated with each other.

Hausman specification test is one of the instruments that helps us to decide which of two considered models, fixed effects or random effects, is more convenient to use. The null hypothesis of this test states the coefficients estimated by the efficient random effects estimator equals to the one estimated by the consistent fixed effects estimator against the alternative hypothesis saying the opposite. *Hausman test* produced negative values testing the basic model of project on SECA. Baum (2006) mentioned that *Hausman test* often fails, giving negative values of χ^2 statistic and so providing conflicting results. We think that FE model will be still more suitable than RE model whatever the result of our *Hausman test* is.

4.3 Data Analysis

In our case, declaration of the dataset to be panel data gives strongly balanced panel variable SVJ representing each observed apartment building (in the mean that the values are available every year out of 6 for all of the given SVJs). The model uses t as time determinant given by time periods t = 1, 2, 3 before insulation and t = 4, 5, 6 after insulation. In this part we are applying the theoretical model as describe in section (4.2) that is the FE model.

Time variable is not included in our models since the level of capital endowment remains the same over time before and after insulation. We also do not have any information when the capital endowment was installed before the insulation, so the time variable cannot control for an autonomous technological progress in the capital endowment. *SECA* is the specific energy consumption adjusted for different weather conditions every year. Inclusion of continuous time variable in our models would therefore lead to taking away the partial effect of insulation project on *SECA*, as the assumption after insulation always follow consumption before the insulation. Moreover, with respect to time, our panel is not balanced as the insulations were installed in various years during the period 2006 to 2012. Small sample size did not allow us to use time dummies. Hence, this is the reason why we leave the time out of our models. If any, autonomous or induced technological progress in thermal insulation is then reflected in the fixed effects of the units.

We estimate several models to examine the effects of project and investment in insulation on energy consumption. At first, we analyse the effect of *PROJECT* dummy on specific annual energy consumption (*SECA*). To recognize the learning effect connected to project realization on *SECA* we introduce at first model including variable *Learning* and then another model with variables *Learning2* and *Learning3* respectively. Then we set up model with the *Realization09* and *Realization11* included in interaction terms with *PROJECT* to observe the effect of technology innovation. Next we try to capture an impact of invested money by entering the continuous variable *Inv6* using also various additional independent variables like *SubsidyD* in this model specification. Finally, we present the model to find relation between investment, government subsidy, time of realization of the insulation and *SECA*.

4.3.1 Verification of FE models' assumptions

Before using FE method to estimate the model, we have to verify all six assumptions each FE transformation requires.

To get an unbiased and consistent pooled OLS estimator, the assumptions for using FE model have to be verified. Thereafter, we can interpret results from all regressions. Appendix B contains the list of FE model assumptions and their justification is described below.

For each of our model, FE.1 holds and the model is linear in parameters, for each period of time, we observe the same random sample as described in data collection included in chapter four and so FE.2 is fulfilled too. *PROJECT, Learning, Learning2, Learning3* and *Investment* are changing for each of 45 SVJ's over time as well as other variables like interactions of realizations, measures or subsidies are changing at least for some of individuals (SVJ) over time. Therefore, no perfect linear relationship exists among the explanatory variables and so FE.3 holds for each of the models applied. When we run this FE regression in Stata for each of the model separately, we receive $E(u_{it}|\boldsymbol{X}_i, a_i) = 0$, the information that explanatory variables are exogenous and so FE.4 is valid. FE.5 does not hold since *Breusch- Pagan test* rejects the null hypothesis of constant variance in every regression we run. Since in practice no autocorrelation is rarely observed (FE.6 violated) we apply cluster-robust standard errors for the estimation (Schmidheiny, 2014). Therefore, this cluster tool helps to resolve the problem of heteroskedasticity and autocorrelation in all models. Hence, we can use FE transformation to estimate our models.

When all assumptions hold we move to the estimation of the models and start to estimation of models and interpretation of the regression results.

4.3.2 Specific energy consumption per year and the implementation of insulation

In the model 1, we focus on the effect of project on SECA, estimating following equation:

$$SECA_{it} = \alpha_1 + \beta_1 PROJECT_{it} + a_i + u_{it} \quad (4.6)$$

This equation (4.6) describes our basic FE model where the subscript i describes the building (SVJ) units, $i = 1,2, \dots ,45$, t describes time periods with $t = 1,2, \dots ,6$, a_i presents the fixed effects and u_{it} is idiosyncratic error. The same goes for all of the subsequent models.

We expect the dummy variable *PROJECT* to be correlated with the unobserved effect a_i like location of the building or education of the decision-making SVJ's governing body.

The coefficients $\hat{\alpha}_1$, $\hat{\beta}_1$, as well as the FE a_i are estimated by pooled OLS regression. The main reason to study the effect of *PROJECT* on *SECA* is to find the impact of introducing the insulation on energy savings that is given by coefficient $\hat{\beta}_1$. The coefficient $\hat{\alpha}_1$ shows an average SECA without project including the average effect of individual-specific intercepts (unobserved effects) on *SECA* (Wooldridge, 2012).

FE regression results arising from Stata comply with our expectations that *PROJECT* has very high and significant effect on energy consumption. Keep in mind that in all cases where we interpret effect on SECA the effect is related to normalized energy consumption adjusted for weather conditions. In Table 4.3 we see negative effect of our independent variable considered in this model. Introduction of insulation represented by dummy variable *PROJECT* decreases the *SECA*. Coefficient $\hat{\beta}_1$ is statistically significant at 1% significance level. *PROJECT* causes approximately 0.135 GJ/m^2 decrease of *SECA* per year when the insulation is performed after controlling for other factors. FE regression gives us *within R-squared* equalled to 0.91 indicating that approximately 91 % of the *SECA* variation within each apartment building in our dataset over the 6 years, eliminating fixed effects, is explained by the independent variables that are incorporated in model 1. Furthermore, *rho* obtained from this FE regression, determining the ratio of total variance in *SECA* explained by the fixed effect a_i, corresponds to the value of 0.858. It means that only about 14.2 % of total variation in *SECA* is due to the idiosyncratic error.

To estimate approximate percentage change the project introduction has, we will simply arrange the equation (4.6) to the following form (model 1b):

$$SECAind_{it} = \alpha_1 + \beta_1 PROJECT_{it} + a_i + u_{it} \tag{4.7}$$

where $SECAind_k = \frac{SECA_k}{SECA_1}$, $k = \{1,2, \dots ,45\}$. This model satisfies the same assumptions as previous model. The subscript i describes the building (SVJ) units, $i = 1,2, \dots ,45$, t describes time periods with $t = 1,2, \dots ,6$, a_i presents the fixed effects and u_{it} is idiosyncratic error. The coefficients $\hat{\alpha}_1$, $\hat{\beta}_1$, as well as the FE a_i are again estimated by pooled OLS regression. In this model we are mainly focused on estimation of the percentage effect of project on energy consumption given by the coefficient $\hat{\beta}_1$. The Stata results show that project of insulation leads to almost 35 % decrease in energy consumption after controlling for other factors. Independent variables are both significant at 5% significance level. However, *rho* is quite small (*rho*= 0.377) and so lots of variation in SECA is caused by idiosyncratic error. Figure 4.3 exhibits the relation between normalized energy consumption before and after the insulation for each SVJ. We see the pivot caused by insulation (decrease of energy consumption after the insulation by 36 %). This is confirmed by our econometric analysis.

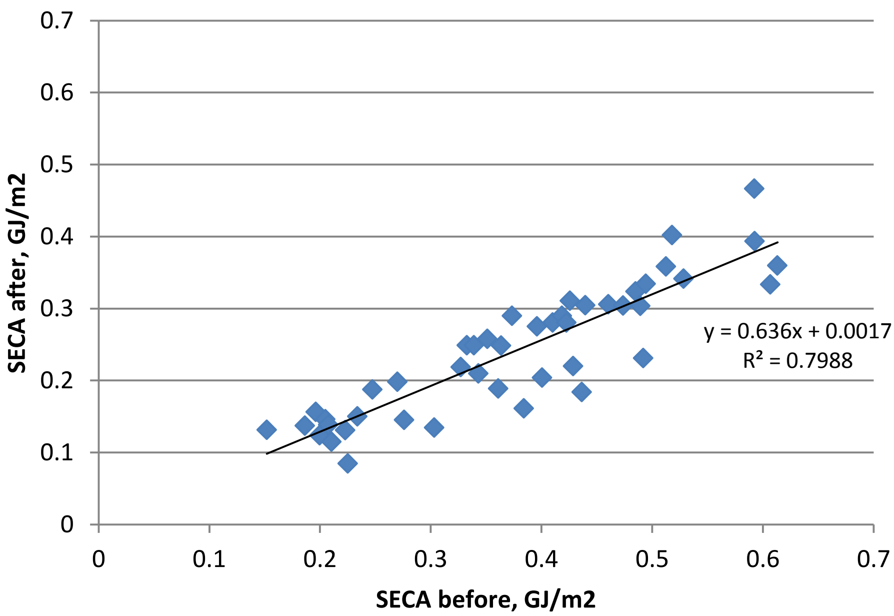

Figure 4.3 - Depict of three year average of SECA before and SECA after the insulation for each SVJ

Source: Author’s computation using the data from the dataset

To observe the trend of people learning, or their increasing level of energy consumption that leads to shrinkage of energy savings, we introduce model with variable *Learning* that captures the effect of learning on energy consumption. *Learning* is defined by ordered numbers 1, 2, 3 when the building was insulated, defined by the year after the insulation and equals to 0 otherwise. We introduce model 2 that reflects this relationship in the following equation:

$$SECA_{it} = \alpha_1 + \beta_1 PROJECT_{it} + \beta_2 Learning_{it} + a_i + u_{it} \tag{4.8}$$

The subscript i describes the building (SVJ) units, $i = 1,2,\dots,45$, t describes time periods with $t = 1,2,\dots,6$, a_i presents the fixed effects and u_{it} is idiosyncratic error. *Learning* is the term determining the effect of learning after the insulation was installed. FE assumptions of this model are justified. The coefficients $\hat{\alpha}_1$, $\hat{\beta}_1$, $\hat{\beta}_2$ as well as the FE a_i are again estimated by pooled OLS regression. We are mainly interested in the value of coefficient $\hat{\beta}_2$ that interprets the impact of learning on *SECA* keeping other factors fixed. In Table 4.3 we observe the FE regression results gained from Stata. We would suppose the rebound effect appear and the sign of the interaction term becomes positive (opposite effect on energy savings). To our surprise, people are learning over time and the sign of the interaction term is negative. The effect of the *Learning* is insignificant so the insulation in this model describes only the effect of *PROJECT*. The coefficient $\hat{\beta}_2$ just weakly determines the negative effect of *Learning* on *SECA* as our data sample is not large enough. Thus, learning weakly contributes to reduction of the energy consumption by 0.001 GJ/ m^2 per year.

Next model 2b estimates the learning impact in the given years after the introduction of insulation.

$$SECA_{it} = \alpha_1 + \beta_1 PROJECT_{it} + \beta_2 Learning2_{it} + \beta_3 Learning3_{it} + a_i + u_{it} \tag{4.9}$$

The subscript i describes the building (SVJ) units, $i = 1,2,\dots,45$, t describes time periods with $t = 1,2,\dots,6$, a_i presents the fixed effects and u_{it} is idiosyncratic error. Variables *Learning2* and *Learning3* identify the second and third year after the insulation respectively. The variable *Learning2* equals to 1 in the second year after insulation (t=5) and 0 otherwise and variable *Learning3* equals to 1 in the third year after insulation (t=6) and 0 otherwise. The coefficient $\hat{\beta}_1$ denotes the effect of introduction of insulation on SECA, $\hat{\beta}_2$ denotes the effect of learning on SECA the second year after insulation and $\hat{\beta}_3$ denotes the effect of learning on SECA third year after insulation. The coefficient $\hat{\alpha}_1$ shows an average SECA including the average effect of individual-specific intercepts (unobserved effects) on *SECA*.

The sum of the coefficients $\hat{\beta}_1 + \hat{\beta}_2$ describes the effect of learning two years after insulation and $\hat{\beta}_1 + \hat{\beta}_3$ shows the effect three years after the insulation realized. Variables *PROJECT* and *Learning2* are both significant at 10% significance level but *Learning3* becomes insignificant in this model. Regression results from Stata says the first year of insulation, people save about 0.13 GJ/m^2 per year while in the second year after insulation people save even more, exactly their energy savings increase by 0.01 GJ/m^2 per year. The third year we observe only weak effect since the variable *Learning3* is insignificant. Though, we see the opposite effect of decreasing the amount of energy savings during the third year. This effect reduces energy savings by another 0.003 GJ/m^2 per year, but the impact is smaller than in second year. Therefore, we would observe U-shape relationship of the energy savings during these 3 years. We can only argue about the reasons why the energy consumption went back up after the second year of insulation. One of the possible reasons could be the rebound effect of recently insulated buildings mentioned in the literature review referring to Gillingham and Palmer (2013) in the beginning of this work.

Our sample covers the 6 year period (2006-2012) when the insulation was installed. So we may test the technology progress by using variables Realization09 and Realization11, where the first refer to insulation before 2009 and the second after 2011. We introduce these variables in model 3 in relation with *PROJECT* leading to the specification of the equation (4.6):

$$SECA_{it} = \alpha_1 + \beta_1 PROJECT_{it} + \beta_2 PROJECT \times Realization09_{it} + \beta_3 PROJECT \times Realization11_{it} + a_i + u_{it} \qquad (4.10)$$

This equation (4.10) describes specification of basic FE model where the subscript *i* describes the building (SVJ) units, $i = 1,2, \ldots, 45$, *t* describes time periods with $t = 1,2, \ldots, 6$, a_i presents the fixed effects and u_{it} is idiosyncratic error. *PROJECT×Realization09* and *PROJECT×Realization11* are interaction terms indicating, whether the insulation was introduced before 2009 or after 2011 respectively. FE assumptions of this model are justified in previous section. The coefficient $\hat{\beta}_1$ corresponds to effect of project introduction on *SECA*. The coefficients $\hat{\beta}_2, \hat{\beta}_3$ are complementary insulation effects contributing to effect of project introduction on *SECA*. Thanks to those differences we can judge whether the insulation technologies have improved over the decade and if they are more efficient nowadays. We would expect the effect $\hat{\beta}_2$ to be smaller than $\hat{\beta}_3$ since we predict technology improvement over time. The Stata provides controversial results showing opposite. The interaction *PROJECT×Realization09* is insignificant with p-value = 0.452. The interaction *PROJECT×Realization11* is significant at 5% significance level and *PROJECT* is significant even at 1% significance level. This regression shows the insulation led to approximately similar effects before 2012 but the projects realized since 2012 led to about one third lower energy savings than the project implemented before. It might indicate the buildings insulated at the beginning of the subsidy programmes (before 2009) were really wasteful before the implementation of insulation and so the potential to energy savings was much higher than for recently insulated buildings (after 2011) that were not so wasteful at all.

We can try to confirm this hypothesis by another econometric analysis of the following model 3b:

$$SECA_{it} = \alpha_1 + \beta_1 Inv6_{it} + \beta_2 Inv6 \times Realization09_{it} + \beta_3 Inv6 \times Realization11_{it} + a_i + u_{it} \tag{4.11}$$

This equation (4.11) describes specification of basic FE model where the subscript *i* describes the building (SVJ) units, $i = 1,2, \dots ,45$, t describes time periods with $t = 1,2, \dots ,6$, a_i presents the fixed effects and u_{it} is idiosyncratic error. Assumptions hold and so we can estimate this model by FE regression. To confirm our hypothesis we need $\hat{\beta}_1 < 0, \hat{\beta}_2 < 0$ or insignificant and $\hat{\beta}_3 > 0$. Then we can confirm buildings insulated before 2012 had much higher potential to save energy since these buildings were much more wasteful than the buildings insulated after 2011. Both $\hat{\beta}_1, \hat{\beta}_2$ are negative and $\hat{\beta}_2$ is insignificant as we supposed. The coefficient $\hat{\beta}_3$ is positive, hence, we can confirm our hypothesis.

We did not find any systematic difference of different types of insulation projects (such as windows replacement, or cellars insulation) on energy consumption that might be also because of too little observations for each particular project type given by small sample size.

Dependent variable: SECA				SECAind
Independent variables	Model 1	Model 2	Model 2b	Model 1b
Constant	.3766753***	.3766753***	.3766753***	.9816114***
	(.0036877)	(.0045857)	(.0045943)	.0082614
PROJECT	-.135415***	-.131506***	-.130389***	-.350125***
	(.0091543)	(.0109738)	(.0096333)	(.0165228)
Learning	-	-.0019546	-	-
	-	(.0030687)	-	-
Learning2	-	-	-.011168**	-
	-	-	(.0045434)	-
Learning3	-	-	-.0039092	-
	-	-	(.0061489)	-
Fixed effects	yes	yes	yes	yes
R-squared	0.9104	0.9105	0.9110	0.8490
Number of observations	270	270	270	270
Number of groups	45	45	45	45
Rho	0.8584577	0.85801514	0.85822486	0.37711977
Hausman test	negative	negative	fails to reject H_0 ($p > 0.05$)	fails to reject H_0 ($p > 0.05$)

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 4.3 - FE regressions - first part

Source: Author's computation using the data from the dataset

Independent variables	Model 3	Model 3b
Constant	.3766753***	.3524656***
	(.00423)	(.0069723)
PROJECT	-.142969***	-
	(.0134364)	-
PROJECT ×Realization09	-.0153116	-
	(.020157)	-
PROJECT×Realization11	.0476092**	-
	(.0196847)	-
Inv6	-	-.011233***
	-	(.0018946)
Inv6×Realization09	-	-.003414
	-	(.0060351)
Inv6×Realization11	-	.00615**
	-	(.0029648)
Fixed effects	yes	yes
R-squared	0.9186	0.8126
Number of observations	270	270
Number of groups	45	45
rho	0.88128797	0.73090557
Hausman test	negative	reject H_0 ($p < 0.05$)

Table 4.4 - FE regressions - second part

Source: Author's computation using the data from the dataset

4.3.3 Specific energy consumption per year, subsidy and investment in insulation

Further model 4 aim at the financial means used for reconstructions connected with insulation and its effect on *SECA*. The essential analysis is focused on estimation of this equation:

$$SECA_{it} = \alpha_1 + \beta_1 Inv6 + a_i + u_{it} \tag{4.12}$$

This equation (4.12) describes the FE model of energy consumption in relation with investment in insulation where the subscript i describes the building (SVJ) units, $i = 1,2, \dots ,45$, t describes time periods with $t = 1,2, \dots ,6$, a_i presents the fixed effects and u_{it} is idiosyncratic error. Independent variable *Inv6* is supposed to be correlated with an unobserved effect a_i. FE transformation let us to obtain the influence of the investment on *SECA*. We use variable *Inv6* rather than *Investment* to get more easily interpreted figures. We have to pay attention during interpretation of this effect since

Inv6 represents a proportion of total investment (exactly one millionth). The coefficient $\hat{\beta}_1$ is considered as a rough change in *SECA* as a consequence of one more million CZK invested in insulation after controlling for other factors (observed as well as unobserved). Probing the investment expended on insulation leads to discovery how much the investment participates on total savings of energy used for heating.

The model 4 tells us the investment really reduces total energy consumption. The precise interpretation is that the one million of invested money into insulation of a building reduces *SECA* by more than 0.01 GJ/m^2 per year. The p-value of coefficient $\hat{\beta}_1$ is equal to zero and so the coefficient on *Inv6* is highly significant and it is reasonable to keep this variable in the model. Considering the average heated floor area that is 3,628 m^2 we get average energy savings of 36.28 GJ per year as the effect of each invested million in the insulation project in multi-family apartment buildings. The average value of investment in the insulation project in our sample is equal to amount of 8,188,175 CZK that implies the average effect of about 297 GJ per year per project. An alternative interpretation, when assuming the average cost of energy use for heating that corresponds to 593.6 CZK per GJ, each insulation project led on average to financial savings of about 176,299 CZK per year. In other words, each 100 CZK invested in the thermal insulation led to 2.15 CZK of financial savings that implies around 46 years of payoff period.[20]

Some of our researched SVJ got an endowment for a realization of insulation of their apartment buildings and it seems interesting to examine whether this additional money obtained as an extra financial mean would have downward or upward effect on energy consumption. In downward effect we expect that people who receive such a subsidy can invest more into more expensive but also more efficient energy saving insulation measures (savings per unit costs). The upward effect may be a result of inefficient decision on investment as a part of investment costs were subsidized by government grant. We use three models to examine this effect. The first model 4b is given by following equation:

$$SECA_{it} = \alpha_1 + \beta_1 Inv6 + \beta_2 SubsidyD + a_i + u_{it} \tag{4.13}$$

[20] Source: http://www.cenyenergie.cz/teplo/ - the information about the average price of energy used for heating (counted for distance heating systems since the majority of our buildings are using this type of heating).

that examines whether obtained subsidy represented by dummy variable *SubsidyD* has any effect on final energy consumption. The subscript i describes the building (SVJ) units, $i = 1,2, \dots ,45$, t describes time periods with $t = 1,2 \dots 6$, a_i presents the fixed effects and u_{it} is idiosyncratic error. The FE assumptions are justified. The model 4b presents negative effect of both included independent variables – *SubsidyD* as well as *Inv6* on *SECA*. Both coefficients of independent variables are highly significant since p-values are lower than 0.01 and so it is reasonable to have them in model. The coefficient $\hat{\beta}_1$ refers to approximate 0.0055 GJ/m^2 per year drop in *SECA* caused by investment of one million into insulation and $\hat{\beta}_2$ is equal to 0.0955 GJ/m^2 per year decrease in *SECA* when subsidy is provided for financing the insulation project. Therefore, the overall effect for the projects with the provided subsidy is a decrease in SECA approximately by 0.011 GJ/m^2 per year. Thus, the multi-family buildings using the subsidy as a part of their funding, they saved about 40 GJ/m^2 per year per one invested million CZK that is about 20 GJ/m^2 more than those without the subsidy. Hence, the average value of investment in insulation project given as 8,188,175 CZK led to energy savings of about 327.5 GJ/m^2 per year. Using average energy cost in Czech Republic of 593.6 CZK per GJ the financial savings correspond to 194,420 CZK per year. In other words, 100 CZK of invested money into the insulation project led to 2.37 CZK of financial savings.

Next we test model 4c whether *SECA* also depends on the provided amount of the additional financial means represented by following equation:

$$SECA_{it} = \alpha_1 + \beta_1 Inv6 + \beta_2 SubsidyCZK6 + a_i + u_{it} \qquad (4.14)$$

considering total amounts of investment and subsidy in the form of modified variables *Inv6* and *SubsidyCZK6* to get simply interpreted coefficients. The subscript i describes the building (SVJ) units, $i = 1,2, \dots ,45$, t describes time periods with $t = 1,2, \dots ,6$, a_i presents the fixed effects and u_{it} is idiosyncratic error. The FE assumptions are justified. This holds also for the following model 4d described by equation (4.15). With this model we can test which subsidies are at least efficient.

$$SECA_{it} = \alpha_1 + \beta_1 Inv6 + \beta_2 SubsidyCZK6 + \beta_3 SubsidyIR + a_i + u_{it} \qquad (4.15)$$

The amount of subsidy is not available for all of the SVJ who got the subsidy, since many different endowment programmes and different ways of providing subsidy were used. Some of them (e.g. Panel or New Panel) provided subsidy by the means of decreased interest rates. When SVJ thought over to take a loan from a bank to fund the insulation project it seemed reasonable to apply for this subsidy. However, the final amount of support is unknown. That is why new dummy variable *SubsidyIR* has been introduced.

In the third model 4c we have insignificant variable *SubsidyCZK6* (p-value of coefficient on this variable corresponds to value of 0.85) so it turns out we cannot say anything about the influence of money provided from this source of financing.

From the following model 4d we can at least observe the subsidies without specific amounts of money. Coefficient $\hat{\beta}_3$ on *SubsidyIR* is very significant and negative. This kind of subsidies (such as New Panel or Panel) causes a decrease in *SECA* approximately by 0.0889 GJ/m^2 per year. Therefore, we can say that the government funding programmes in the way of decreased interest rates are more efficient than the other options. When observing this effect we have to keep in mind the reference to literature review that omitting the free-riding can lead to magnified effect of subsidy on energy savings. There will still be people who would invest into the thermal insulation even without subsidy.

In models 4c and 4d we observe that *SubsidyCZK6* is insignificant in both cases, hence, it is the reason why we introduced variable *Share1*. And so we carry on to estimation of model 5.

We want to estimate a partial effect of fraction of subsidy to investment given by the following formula:

$$Share1 = \frac{SubsidyCZK}{Investment} \qquad \text{if SubsidyCZK6 > 0 and Investment > 0}$$
$$= 0 \qquad \text{otherwise} \tag{4.16}$$

The final model 5 is specified as:

$$SECA_{it} = \alpha_1 + \beta_1 PROJECT + \beta_2 Share1 + a_i + u_{it} \tag{4.17}$$

where coefficients $\hat{\beta}_1$ and $\hat{\beta}_2$ are consecutively interpreted such as an approximate change in *SECA* caused by insulation project and the effect of each percentage point given by a part of investment being subsidized. We suppose that the higher proportion of subsidized investment, the lower energy savings as the lower subsidy may lead to stronger engagement in the renovation as well as to lower potential for the rebound effect.

The model 5 brings us to interesting outcomes (Table 4.5). The sign of variable *Share1* is positive so it means that one unit increase in *Share1* leads to 0.0041 GJ/m^2 per year increase in energy consumption represented by *SECA*. The coefficient of *Share1* is to our regret insignificant but we can still consider it along with the fact the data sample we use is not large enough. The effect of *Share1* is opposite to the effect of investment in insulation project. This impact reminds us the rebound effect mentioned in literature review claiming that with introduction of insulation (which leads to lower needs of energy thanks to its decreased emissivity glazing) people tend to enjoy higher inside temperatures. To sum it up the higher the share of subsidy provided by the government funding programmes such as Green for Savings or New Green for Savings in total financial funding of insulation the lower incentives people have to save energy. They rather increase their standards of living (in the mean of higher thermal convenience).

The results from proposed models obtained from Stata are written down in attached Table 4.5.

Dependent variable: SECA					
Independent variables	Model 4	Model 4b	Model 4c	Model 4d	Model 5
Constant	.3503678***	.3584581***	.3503733***	.3554744***	.3766753***
	(.0074397)	(.0059805)	(.0074502)	(.0057181)	(.0045298)
Inv6	-.010112***	-.005353***	-.010252***	-.007287***	-
	(.0018172)	(.0018203)	(.0019848)	(.0018538)	-
SubsidyD	-	-.095450***	-	-	-
	-	(.0167314)	-	-	-
SubsidyCZK6	-	-	.0016141	-.0052588	-
	-	-	(.0088519)	(.0101095)	-
SubsidyIR	-	-	-	-.077378***	-
	-	-	-	(.0212963)	-
PROJECT	-	-	-	-	-.139641***
	-	-	-	-	(.0098757)
Share1	-	-	-	-	.0041084
	-	-	-	-	(.0034638)
Fixed effects	yes	yes	yes	yes	yes
R-squared	0.7956	0.8387	0.7957	0.8239	0.9117
Number of observations	270	270	270	270	270
Number of groups	45	45	45	45	45
Rho	0.69154907	0.77321589	0.69126279	0.75156235	0.86170284
Hausman test	fails to reject H_0 ($p > 0.05$)	reject H_0 ($p < 0.05$)	fails to reject H_0 ($p > 0.05$)	reject H_0 ($p < 0.05$)	fails to reject H_0 ($p > 0.05$)

* p < 0.1, ** p < 0.05, *** p < 0.01

Table 4.5 - FE regressions - third part

Source: Author’s computation using the data from the dataset

5 CONCLUSION

The goal of this thesis is to analyse the effect of thermal insulation installed in multi-family apartment buildings (represented by SVJ) between 2006 and 2012 in the Czech Republic on energy used for heating. Thermal insulation is one of the basic steps to achieve low-carbon energy system since currently energy consumption of residential buildings forms almost one third of total national energy consumption. This research aims at examining the energy savings potential associated with thermal insulation, by the econometric analysis of the collected data from already insulated multi-family apartment buildings. In specific terms, this thesis investigates the relationship between the introduction of thermal insulation and energy consumption through the effect of the insulation project or investment connected with the insulation project on energy savings. The research also explores the importance of governmental funding programmes for multi-family building reconstructions in the Czech Republic and produces the estimated effect of those funding programmes on energy consumption of the buildings. The complementary survey helped us to discover the main obstacles in decision-making process of associations of unit owners connected with the implementation of insulation in their buildings.

The results show, on average, the insulation resulted in energy savings of about 0.135 GJ per m^2, or by 35 %. Alternatively, our findings show that each million CZK invested in thermal insulation resulted in energy savings of about 10 MJ per m^2 or 21,500 CZK of financial saving each year. Even without discounting, these savings imply quite long payoff period of about 46 years.

When subsidy from any governmental funding programmes was provided, each million CZK invested into insulation implies energy savings of about 11 MJ per m^2 or 23,700 CZK of financial savings each year. It seems the subsidy allows investment in larger insulation projects that resulted in relatively larger energy savings. The results also show the subsidies in form of lower interest rates are more efficient with respect to energy use reduction than the other subsidy options.

When observing the relationship between the years after implementation of insulation and energy consumption we conclude that learning or rebound effect are not strong at all. The third year after insulation the decreasing effect of learning realized in the second year on energy consumption disappears. We hypothesise that the U-shape effect regarding insulation project on energy consumption could be due to people learning but is countered by the rebound effect on the third year, when people began to enjoy higher heat levels.

Our results also confirm that buildings insulated before 2012 had much higher potential to save energy as the insulation of those buildings led to higher energy savings. We did not find any systematic difference between particular insulation measures. The probable reason could be related with the small number of observations in our sample. Therefore, finding the volume and contribution of single insulation measures to energy savings remains for further research.

Associations of unit owners are not sufficiently motivated to insulate their buildings by the governmental funding programmes. The results show that more than 80 % of respondents from insulated buildings would undertake the thermal insulation regardless the subsidy provision. The total investment in insulation project may be smaller when the subsidy is not provided. This can indicate that SVJ without a subsidy may rather invest into less expensive and less efficient insulation project as confirmed by our analysis. However, with a subsidy there remains the potential for free-riding behaviour.

Lack of financial means is said to be the main barrier in decision-making process whether to invest in thermal insulation. We admit that debt issues have been the most discussed obstacles during the decision on insulation made by the associations of unit owners. Almost one half of respondents from non-insulated buildings stated as the main reason the financial problems. Other problems perceived by respondents were inconveniences and disturbances caused by the construction work itself and fear of subpar quality of the insulation.

The positive effect of thermal insulation was mainly perceived in energy savings and financial savings afterwards. Majority of investors in thermal insulation (90 %) believe it will pay off. Assuming the same price of heat, the pay off period is estimated to be about 46 years long. It can be up to more research whether homeowners will concern themselves with such long-run investment payoff or if insulation of the building will be considered as a bonus in price of the property. In fact, 86 % of respondents are convinced the insulation increased the market price of their flat. Moreover, analysis has proved that insulation improved the living conditions of the families particularly in terms of thermal conditions.

Despite the small sample size, we confirm the large saving potential in the multi-family apartment buildings that might be potentially induced by thermal insulation projects. Thus, this study could serve as supporting evidence for SVJs deciding whether to insulate. Exploring the energy savings potential in other programs, such as Integrated Regional Operational Programme (IROP) or New Green for Savings Programme, remains for further research.

BIBLIOGRAPHY

Alberini, A., Bigano, A., & Boeri, M. (2013). *Energy Efficiency: Looking for free-riding: Energy efficiency incentives and Italian homeowners*. Fondazione Eni Enrico Mattei Milano. pp. 571-590

Alberini, A., & Bigano, A. (2014). *How Effective are Energy-Efficiency Incentive Programs?: Evidence from Italian Homeowner*. Fondazione Eni Enrico Mattei. Retrieved from: https://www.rwth-achen.de/global/show_document.asp? id= aaaaa aaaaajizxy. pp. 2-5

Allcott, H., & Greenstone, M. (2012). *Is there an Energy Efficiency Gap?*. Cambridge MA: National Bureau of Economic Research.

Arimura, T. H., Li, S., Newell, R. G., & Palmer, K. (2011). *Cost-Effectiveness of Electricity Energy Efficiency Programs*. National Bureau of Economic Research Retrieved from: http://www.nber.org/papers/w17556

Attali, S., & Geller, H. (2005). *The Experience With Energy Efficiency Policies and Programmes in IEA Countries: Learning from the Critics*. Retrieved from: https://www.iea.org/publications/freepublications/publication/IEAEnergyPolicies_ Learning_from_critics.pdf

Baum, C.F. (2006). *An Introduction to Modern Econometrics Using Stata*. Stata Press.

Civil Code (New) - No 89/2012 Sb. (up-to-date). (2012). Retrieved from: http://www.zakonyprolidi.cz/cs/2012-89

Co je subregulace tepla a proč je dobré ji mít v bytovém domě?? | Subregulace tepla EIM. (2015). Retrieved from: http://www.subregulace.cz/co-je-subregulace-tepla-a-proc-je-dobre-ji-mit-v-bytovem-dome/

COP21 | United Nations Conference on Climate Change. (2015). Retrieved from: http://www.cop21.gouv.fr/en/

Energetický audit - Asociace energetických auditorů : energetický audit, poradenství, legislativa. (2012). Retrieved from: http://www.aea.cz/energeticky-audit

European Climate Foundation. (n.d.). *Roadmap 2050*. Retrieved from: http://www.roadmap2050.eu/

European Commission. (n.d.). *2020 Climate & Energy Package*. Retrieved from: http://ec.europa.eu/clima/policies/strategies/2020/index_en.htm

European Commission. (n.d.). *Energy Efficiency: Buildings*. Retrieved from: https://ec.europa.eu/energy/en/topics/energy-efficiency/buildings

European Commission. (n.d.). *Strategic Energy Technology Plan*. Retrieved from: http://ec.europa.eu/energy/en/topics/technology-and-innovation/strategic-energy-technology-plan

European Council. (2014). *Conclusions on 2030 Climate and Energy Policy Framework*. Retrieved from: http://www.consilium.europa.eu/uedocs/cms_data/docs/pressdata/en/ec/145356.pdf

Eurostat. (2015). *Housing statistics - Statistics Explained*. Retrieved from: http://ec.europa.eu/eurostat/statistics-explained/index.php/Housing_statistics

Gardner, G. T., & Stern, P. C. (2009). *The Short List: The Most Effective Actions U.S. Households Can Take to Curb Climate Change*. Taylor & Francis Group. Retrieved from: http://www.environmentmagazine.org/Archives/Back%20Issues/September-October%202008/gardner-stern-full.html

Gerarden, T. D., Newell, R. G., & Stavins, R. N. (2015). *Assessing the Energy-Efficiency Gap*. Resources for the future. Retrieved from: http://www.rff.org/files/sharepoint/WorkImages/Download/RFF-DP-15-07.pdf

Gillingham, K., Newell, R., & Palmer, K. (2006). *Energy Efficiency Policies: A Retrospective Examination.* Resources for the future. pp. 161-192

Gillingham, K., Newell, R. G., Palmer, K. (2009). *Energy Efficiency Economics and Policy*. NBER Working Paper No. 15031.

Gillingham, K., & Palmer, K. (2013). *Bridging the Energy Efficiency Gap: Insights for Policy from Economic Theory and Empirical Analysis*. Resources for the future. Retrieved from: http://www.rff.org/files/sharepoint/WorkImages/Download/RFF-DP-13-02.pdf

Gillingham, K., Rapson, D., & Wagner, G. (2014). *The Rebound Effect and Energy Efficiency Policy*. Resources for the future. Retrieved from: http://www.rff.org/files/sharepoint/WorkImages/Download/RFF-DP-14-39.pdf

Horáková, A., Mrázek, K., & Marková, K. (2013). *MPO Efekt - Klimatologické údaje*. Program EFEKT.Retrieved from: https://www.mpo-efekt.cz/cz/ekis/publikace/48550

Hynek, D., Levy, M., Smith, B., & Wisconsin Division of Energy Services. (2012). *"Follow the Money": Overcoming the Split Incentive for Effective Energy Efficiency Program Design in Multi-family Buildings*. ACEEE Summer Study on Energy Efficiency in Buildings.Retrieved from: http://aceee.org/files/proceedings/2012/data/papers/0193-000192.pdf

IPPC (2007).*Climate Change 2007: Impacts, Adaptation and Vulnerability: Synthesis Report – Summary for Policymakers – An Assessment of the Intergovernmental Panel on Climate Change*. Retrieved from: http://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr_spm.pdf

Jaffe, A. B., & Stavins, R. N. (1994). *Energy Policy 1994: The Energy-Efficiency Gap - What does it mean?* Harvard University. Retrieved from: http://scholar.harvard.edu/files/stavins/files/the_energy_efficiency_gap.pdf?m=1440012135

Jonášová, M. (2013). *Skutečný potenciál úspor energie v budovách v ČR*. Asociace výrobců minerální izolace.Retrieved from: http://stavba.tzb-info.cz/nizkoenergeticke-stavby/10161-skutecny-potencial-uspor- energie-v-budovach-v-cr#pozn1

Kučma, L. (2012). *The Capital Cost Repayment Period of the Reconstruction of Multiple-Function Building* (Master's thesis, University of Technology, Brno, Czech Republic). Retrieved from: https://www.vutbr.cz/www_base/zav_prace_soubor_verejne.php?file_id=54423

Metcalf, G. E. (1997). *Measuring the energy savings from home improvement investments: Evidence from monthly billing data*. Tufts University. Retrieved from: http://ase.tufts.edu/economics/documents/papers/prior2000/papers1997-01.pdf

Nauleau, M. L. (2014). *Free-riding in tax credits for home insulation in France: An econometric assessment using panel data*. Fondazione Eni Enrico Mattei. Retrieved from: http://papers.ssrn.com/sol3/papers.cfm?abstract_id=2426081

Polimeni, J. M., Mayumi, K., Giampietro, M., & Alcott, B. (2008). *The Jevons' Paradox and the Myth of Resource Efficiency Improvements*. Uberty University. Retrieved from: http://uberty.org/wp-content/uploads/2015/08/ John_M._ Polimeni_ Kozo_Mayumi_Mario_Giampietro.pdf

Sauro, J. (2015). *Customer analytics for dummies: Associations between Binary Variables*.

Schmidheiny, K. (2014). *Panel Data: Fixed and Random Effects*. Short Guides to Microeconometrics, Universität Basel.Retrieved from: http://kurt.schmidheiny.name/ teaching/panel.pdf

Šafařík, M., Čejka, M., & Mazáček, J. (2013). *Potenciál úspor energie v budovách v ČR*. PORSENNA o.p.s. Retrieved from: http://www.mineralniizolace.cz/media/cela-studie-potencialu-uspor-energie-v-budovach-v-cr.pdf

Štrosová, I., Hrdlička, V., & Fatura, M. (2014). *Společenství vlastníků ve staronovém kabátě*. Retrieved from: http://www.epravo.cz/top/clanky/spolecenstvi-vlastniku-ve-staronovem-kabate-94543.html

The Law on Energy Management - No 406/2000 Sb. (up-to-date). (2000). Retrieved from: http://www.zakonyprolidi.cz/cs/2000-406

Torres-Reyna, O. (2007). *Panel Data Analysis: Fixed and Random Effects using Stata*. Retrieved from: https://www.princeton.edu/~otorres/Panel101.pdf

Wang, S., Mathews, R., Cao, K., & Australian Bureau of Statistics (Eds.). (2015). *Household Energy Efficiency Improvements: Evidence from ABS 2012 Household Energy Consumption Survey*. Retrieved from: https://editorialexpress.com/cgi-bin/conference/download.cgi?db_name=ESAMACE2014&paper_id=399

Williams, R.(2015). *Heteroskedasticity*.Retrieved from: https://www3.nd.edu/~rwilliam/ stats2/l25.pdf

Wooldridge, J. M. (2012). *Introductory econometrics: A modern approach - Advanced topics, Advanced Panel Data Methods.* (5th ed.). Australia: South-Western College Pub. pp. 447-511

APPENDICES

Appendix A: Results of decision-making process survey

Categories with responses	Number of responses
Degree of Awareness	
Yes, I am interested in insulation issues. I know particular kinds of measures and their advantages. I gather the information about the experiences of the other SVJ.	42
I have information commonly available from media but I did not search any additional facts.	29
I do not care.	3
Age categories	
0-19	1
20-25	17
26-30	6
31-40	8
41-50	14
51-60	11
61-65	5
66-70	8
>70	4
Gender	
Male	44
Female	30
Identification groups	
Student	7
Working student	12
Working	34
Working person of pension age	8
Retiree	10
Others (e.g. Maternity leave)	3

In this questionnaire the proportion of respondents interested in the issue of insulation forms almost 57 % of total number of respondents and only about 4 % are not interested at all. Predominate age of respondents is ranging in the age category 31-60 representing mainly the working population. And so we can conclude that mainly working people are engaged to those issues concerning thermal insulation of apartment buildings.

Total number of observations	74	
Total number of insulated apartment buildings	51	
	# of responses for Insulated	# of responses for Not Insulated
Realized reconstructions / reconstructions to be considered		
Walls Insulation (complete)	37	16
Walls Insulation (partial)	10	0
Windows Replacement	44	10
Balcony Reconstruction	27	10
Roof Insulation	34	12
Non-Residential Areas	29	7
Thermal Regulation	17	0
Modernization of Heating Systems	9	0
Process of Decision-Making whether to insulate*:		
Insulation of Apartment Building was proposed on Assembly and the realization was immediately approved	23	-
Insulation of Apartment Building was proposed on Assembly but for the approval of realization several meetings were needed.	23	-
Others (*Per Rollam*)	5	-
Reasons for Decision against Insulation*:		
During voting procedure, quorate majority was against insulation.	-	5
No proposals of insulation were raised.	-	9
Others	-	9
Decision-making procedure about Suppliers of Insulation*:		
Committee selected the supplier by hearth.	23	-
Committee hired an independent expert who had analyzed all available suppliers and had forwarded them as a proposal to be approved by Committee	16	-
Others	12	-
Main reasons for decision in favour of suppliers*:		
Good and verified references	20	-
Price offer	15	-
Others	15	-

Funding Arrangements (RF - Repair Fund, S – Subsidy, L – Loan)/ funding arrangement choice if decided to insulate:		
RF	10	8
S+RF	1	8
L	8	0
S+L	5	2
RF+L	15	1
RF+L+S	10	4
S	2	0
Subsidy*:		
Applications for grants	21	-
Received Subsidies	17	-
Change of decision about Insulation in relation with not received subsidy	3	-
Type of subsidy:		
Panel (2006)	4	-
New Panel (2007-2013)	2	-
Green for Savings (2009-2012)	14	-
New Green for Savings (2013)	1	-
New Green for Savings (2014-2020)	0	-
Reasons for not grants requiring*:		
Complicated administration	12	-
Grants were not available	8	-
Expensive handouts preparation	3	-
No idea	4	-
Others	3	-
Satisfied with insulation*	40	-
Thinks that it was paying investment*	46	-
Thinks insulation increased market price of a flat*	44	-
Type of heating*:		
Distance Heating System	42	-
Own boiler for the building	5	-
Each flat has its own separate boiler	3	-
Energy consumption used for heating seems*:		
Lower	47	-
Same	3	-
Higher	1	-

Insulation improved*:		
Cold from the walls	38	-
Cold from the floor	12	-
Summer inside temperatures decreased	17	-
Thermal bridges & Mould	2	-
Without improvement	5	-
Others	3	-
Undesirable effects*:		
None	36	-
Mould	2	-
Condensation of the humidity	12	-
Others	5	-
Further measures to be applied*:		
Thermal regulation	18	-
To detach from distance heating system	9	-
Modernization of Heating Systems	2	-
Purchase of smaller and less expensive source of heating	3	-
Roof or walls insulation	8	-
Consider any further measures	4	-
Others	4	-
Awareness of those information:		
Insulation decreases production of pollution	21	11
Guarantee enough energy for future generations	32	16
Insulation Benefits:		
Energy savings and so financial savings	-	19
Higher thermal convenience	-	12
Increased market price of a flat	-	10
Improved market position	-	4
Others	-	4
Insulation Drawbacks:		
Debts	-	11
Problems associated with insulation works	-	7
None	-	5

*asked only when insulated

Appendix B: Description of methods

B.1 Fixed effects (FE)

Fixed effects estimation also called *within estimation* is based on the following unobserved effects model:

$$y_{it} = \beta_1 x_{it1} + \beta_2 x_{it2} + \cdots + \beta_k x_{itk} + a_i + u_{it}, \qquad t = 1,2,\ldots,T \qquad (1.1)$$

where *i* stands for an individual, *t* represents time period, y_{it} is a dependent variable, x_{it}'s are all independent variables, a_i goes for unobserved effect and u_{it} is express an idiosyncratic error. This method is based on elimination of unobserved effect a_i. The following equation average (1.1) over time for each individual:

$$\bar{y}_i = \beta_1 \bar{x}_{i1} + \beta_2 \bar{x}_{i2} + \cdots + \beta_k \bar{x}_{ik} + a_i + \bar{u}_i, \qquad t = 1,2,\ldots,T \qquad (1.2)$$

And by subtraction of (1.2) from (1.1) we obtain the final equation with removed a_i:

$$\ddot{y}_{it} = \beta_1 \ddot{x}_{it1} + \beta_2 \ddot{x}_{it2} + \cdots + \beta_k \ddot{x}_{itk} + \ddot{u}_{it}, \qquad t = 1,2,\ldots,T \qquad (1.3)$$

which can be estimated by general pooled OLS. As the first four assumptions hold the model gives us unbiased fixed effects estimator of β_j and adding another two FE.5 and FE.6 the estimator become best linear unbiased estimator of β_j.

Assumption FE.1

For each *i*, the model is:

$$y_{it} = \beta_1 x_{it1} + \beta_2 x_{it2} + \cdots + \beta_k x_{itk} + a_i + u_{it}, \qquad t = 1,2,\ldots,T \qquad (1.4)$$

where the parameters β_j are to be estimated and a_i is the unobserved effect.

Assumption FE.2

We observe same random sample across every period of time.

Assumption FE.3

Each explanatory variable changes over time (for at least some *i*), and no perfect linear relationships exist among the explanatory variables.

Assumption FE.4

For each t, the expected value of the idiosyncratic error given the explanatory variables in all time periods and the unobserved effect is zero:

$$E(u_{it}|\boldsymbol{X}_i, a_i) = 0 \tag{1.5}$$

Assumption FE.5

$$Var(u_{it}|\boldsymbol{X}_i, a_i) = Var(u_{it}) = \sigma_u^2 \text{ , for all } t = 1,2, \dots, T \tag{1.6}$$

Assumption FE.6

For all $t \neq s$, the idiosyncratic errors are uncorrelated (conditional on all explanatory variables and a_i):

$$Cov(u_{it}, u_{is}|\boldsymbol{X}_i, a_i) = 0 \tag{1.7}$$

Assumption FE.7

Conditional on $\mathbf{X}_i$ and a_i, the u_{it} are independent and identically distributed as Normal$(0, \sigma_u^2)$

B.2 Random effects (RE)

Random effects estimation is another method described by the following unobserved effects model:

$$y_{it} = \beta_0 + \beta_1 x_{it1} + \beta_2 x_{it2} + \cdots + \beta_k x_{itk} + a_i + u_{it}, \quad t = 1,2, \dots, T \tag{2.1}$$

almost same as a FE model but intercept added. Unlike the FE there is additional assumption RE.8 that assumes explanatory variables and unobserved effect to be uncorrelated. Hence, the model allows us to include time-invariant variables to our model as independent variables. To get rid of a_i we introduce the composite error term defined such as:

$$v_{it} = a_i + u_{it} \tag{2.2}$$

and so rewrite the model into the following equation:

$$y_{it} = \beta_0 + \beta_1 x_{it1} + \beta_2 x_{it2} + \cdots + \beta_k x_{itk} + v_{it}, \quad t = 1,2, \dots, T \tag{2.3}$$

Unobserved effect is contained in v_{it} in each time period and so these errors are serially correlated across time along with the assumption RE.8:

$$Corr(v_{it}, v_{is}) = \frac{\sigma_a^2}{\sigma_a^2 + \sigma_u^2}, \qquad t \neq s \qquad (2.4)$$

where σ_a^2 is variance of a_i and σ_u^2 is variance of u_{it}. To take out this serial correlation we simply define θ that range between 0 and 1 and equals to:

$$\theta = 1 - \sqrt{\frac{\sigma_u^2}{\sigma_u^2 + T\sigma_a^2}} \qquad (2.5)$$

where T represents the number of time periods and then transform (3) into the final equation using (2.5):

$$y_{it} - \theta\bar{y}_i = \beta_0(1-\theta) + \beta_1(x_{it1} - \theta\bar{x}_{it1}) + \beta_2(x_{it2} - \theta\bar{x}_{it2}) + \cdots$$

$$+\beta_k(x_{itk} - \theta\bar{x}_{itk}) + v_{it} \qquad (2.6)$$

which can be estimated by general pooled OLS. RE assumptions are similar to those of FE. FE.1, FE.2, FE.4, FE.5, and FE.6. (FE.7 not necessarily) assumptions are valid for RE too. FE.3 is replaced by RE.1, to FE.4 is appended an additional statement about an expected value of a_i and FE.5 is completed by variance of a_i.

Assumption RE.1

There are no perfect linear relationships among the explanatory variables.

Assumption RE.2

In addition to FE.4, the expected value of a_i given all explanatory variables is constant:

$$E(a_i|\boldsymbol{X}_i) = \beta_0 \qquad (2.7)$$

Assumption RE.3

In addition to FE.5, the variance of a_i given all explanatory variables is constant:

$$Var(a_i|\boldsymbol{X}_i) = \sigma_a^2 \qquad (2.8)$$

Appendix C: Questionnaire - Insulation of apartment buildings

Identification

To which extent are you aware about insulation and its advantages?

Yes, I am interested in insulation issues. I know particular kinds of measures and their advantages. I gather the information about the experiences of the other DUOAs.

I have information commonly available from media but I did not search any additional facts.

I do not care.

Gender:

Male

Female

Age categories:

0-19

20-25

26-30

31-40

41-50

51-60

61-65

66-70

>70

Group identification:

Student

Working student

Working

Working person of pension age

Retiree

Others (e.g. Maternity leave)

Insulation Implementation

Have you implemented insulation in your apartment building?

Yes

No

Insulation of apartment buildings

Which measures have been taken concerning the insulation?

Walls Insulation (complete)

Walls Insulation (partial)

Windows Replacement

Balcony Reconstruction

Roof Insulation

Non-Residential Areas

Thermal Regulation

Modernization of Heating Systems

What is the best description of your process of decision-making whether to insulate?

Insulation of Apartment Building was proposed on Assembly and the realization was immediately approved

Insulation of Apartment Building was proposed on Assembly but for the approval of realization several meetings were needed.

Others (e.g. Per Rollam)

What was the decision-making procedure about suppliers of insulation in your case?

Committee selected the supplier by hearth.

Committee hired an independent expert who had analyzed all available suppliers and had forwarded them as a proposal to be approved by Committee

Others

What were the main reasons for decision in favour of suppliers?

Good and verified references

Price offer

Others

Funding Arrangements of insulation project:

- All funding covered by repair fund
- All funding covered by repair fund with subsidy provided
- All funding covered by loan
- All funding covered by loan with subsidy provided
- All funding covered by combination of repair fund and loan
- All funding covered by combination of repair fund and loan with subsidy provided
- All funding covered by subsidy

Did you required for subsidy for realization of insulation?

- Yes
- No

Subsidy

What was the subsidy you asked for?

- Panel (2006)
- New Panel (2007-2013)
- Green for Savings (2009-2012)
- New Green for Savings (2013)
- New Green for Savings (2014-2020)

Have you received the subsidy you asked for?

- Yes
- No

Would you change the previous decision of insulation implementation based on subsidy provision when you did not receive the subsidy?

- Yes
- No

State the main reasons why you did not ask for subsidy:

- Complicated administration
- Grants were not available
- Expensive handouts preparation

No idea

Others

Satisfaction related to reconstruction

Are you satisfied with the reconstruction, do you consider done measures to be complete and sufficient?

Yes

No

If you are not satisfied state your proposals to additional needed measure?

Open point

Heating and energy consumption related to air heating

State type of your heating system:

Distance Heating System

Own boiler for the building

Each flat has its own separate boiler

After insulation your energy consumption used for heating in GJ is:

Smaller

Same

Higher

The insulation improved thermal comfort of living:

By elimination of cold from walls

By elimination of cold from floors

Inside temperature during hot summer days got better

No improvements

Undesirable effects of insulation

Have you observed any undesirable effects of insulation?

Mould appeared after insulation

Condensation of the humidity inside the building

None

Cost-effective investment

Do you think it was cost-effective investment?

Yes

No

Pros

Do you think the insulation increases the market price of your flat?

Yes

No

Which other measures would you take into consideration in future?

Thermal regulation

To detach from distance heating system

Modernization of Heating Systems

Purchase of smaller and less expensive source of heating

Roof or walls insulation

Consider any further measures

Others

Cons

State the specific disadvantages of insulation:

Open point

Insulation and environment

When decision was made, have you take into account the fact the insulation decreases pollution and production of GHG emissions and so helps to protect the environment?

Yes

No

When decision was made, have you take into account the fact the insulation decreases energy consumption and so helps to preserve energy for future generations?

Yes

No

Buildings without insulation

State the main reason, why the apartment building you live in is not insulated?

It is new-build construction.

During Assembly, majority owners vote against insulation.

Nobody came up with the proposal to insulate.

Reasons why not to insulate

What was the main reason for decision against insulation?

During voting procedure, quorate majority was against insulation.

No proposals of insulation were raised.

Others

Needed measures

Which measures do you consider to be needed in the apartment building you live in?

Walls Insulation (complete)

Walls Insulation (partial)

Windows Replacement

Balcony Reconstruction

Roof Insulation

Non-Residential Areas

Thermal Regulation

Modernization of Heating Systems

Which benefits do you think the insulation would bring you?

Energy savings (and so related financial savings)

Increased well-being considering inside thermal conditions

Increase in the selling price of the flat

Improved market position (flat in insulated building is more required)

Which drawbacks are you afraid of?

Insufficient financial means and fear to take a loan

Problems associated with insulation works

None

Which source of funding of investment into insulation would you prefer?

All funding covered by repair fund

All funding covered by repair fund with subsidy provided

All funding covered by loan

All funding covered by loan with subsidy provided

All funding covered by combination of repair fund and loan

All funding covered by combination of repair fund and loan with subsidy provided

All funding covered by subsidy

Would you take into account the fact the insulation decreases pollution and production of GHG emissions and so helps to protect the environment?

Yes

No

Would you take into account the fact the insulation decreases energy consumption and so helps to preserve energy for future generations?

Yes

No