**The Effect of Thermal Insulation in Multi-family Apartment Buildings on Energy Savings**

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Abstract

The goal of this paper is to analyse the energy efficiency of thermal insulation in multi-family apartment buildings insulated between 2006 and 2012 in the Czech Republic. Thermal insulation is one of the basic steps to achieve low-carbon energy system since energy consumption of residential buildings forms almost one third of total national energy consumption nowadays. This research aims at supporting the idea of energy savings induced by thermal insulation, by the econometric analysis of the collected data from already insulated multi-family apartment buildings. In specific terms, we study the relationship between the introduction of thermal insulation and energy consumption. In financial terms, it presents the effect of investment into the insulation project and the energy savings. Our results suggest that the thermal insulation led to high energy savings. On average, the insulation resulted in energy savings of about 0.135 GJ per m2, or by 35 %. Alternatively, our finding shows that each million CZK invested in thermal insulation resulted in energy savings of about 11 MJ per m2 or 21,500 CZK of financial saving each year. Even without discounting, these savings implies quite long payoff period, however. The government funding led to greater energy savings per million CZK invested. Since the average size of funded projects was much larger than not supported ones, it implies that the large-scale projects had greater potential for energy efficiency. Public programs introduced in the Czech Republic were then able to motivate the owners to explore greater potential of the large projects for energy efficiency. The public support provided in a form of lower interest rates of loans were more energy saving than all the other kinds of public grants. Our evidence also supports the notion that the energy savings are lower in those apartment buildings that were insulated at a later stage (after 2012), as oppose to the apartment buildings that were insulated earlier (2007-2011). Energy savings even increased in the second year after the insulation, but then remained at the same level (with the coefficient to be even negative but not significant).

Data

The panel data used in this research were collected mostly from the members of the associations of unit owners, and from the companies contracted to manage the apartment buildings in question.

Our research aimed at already insulated apartment buildings during the past 10 years having information on energy consumption at least one heating season back. It was necessary to obtain energy consumption for heating at least one year before and one year 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.[[1]](#footnote-1) 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, see the descriptive statistics in Table.

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). To obtain the good measure of energy savings, we convert AECH to *normalized annual energy consumption on heating* (NAECH), as $NAECH=AECH×\frac{D\_{N}^{°}}{D\_{A}^{°}}$, 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.

Insulation is represented by eight possible options coding them by 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).

The buildings areas are usually diverse and so to confront the buildings among themselves 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 between SVJ with different floor area related to heating. We express NAECH per floor area that is specific energy consumption per year (*SECA*), see Figure 1 and 2.

Method

These unique data are evaluated using the fixed effects model 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 was adjusted for weather conditions.

As we observed energy consumption of the 45 different apartment buildings (the *cross-sectional* elements) over the six year time period (*time dimension*) we are 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.

In line with our prior expectations, we assume that the factors included in the vector *ai* (such as a location of the building or an education of owners) 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. Since we are using FE model, 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.

*Fixed effects estimation* is based on the unobserved effects model:

$y\_{it}=β\_{1}x\_{it1}+β\_{2}x\_{it2}+…+β\_{k}x\_{itk}+a\_{i}+u\_{it},$ $t=1,2,…, T$

where *i* stands for an individual, *t* represents time period, *yit*is a dependent variable, *xit*’s are independent variables, *ai* goes for unobserved effect and *uit* is express an idiosyncratic error. This method is based on elimination of unobserved effect *ai*. Subtracting the averaged above equation over time for each individual, we obtain the final equation with removed *ai*

$\ddot{y}\_{it}=β\_{1}\ddot{x}\_{it1}+β\_{2}\ddot{x}\_{it2}+…+β\_{k}\ddot{x}\_{itk}+\ddot{u}\_{it},$ $t=1,2,…, T$

which can be estimated by general pooled OLS. To get an unbiased and consistent pooled OLS estimator, the assumptions for using FE model were verified. The final model is linear in parameters where the parameters $β\_{j} $are to be estimated and *ai* is the unobserved effect. Further, for each period of time, we observe the same random sample (n=45\*6) and the kay explanatory variables, such as *PROJECT, Learning, Learning2, Learning3,* and *Investment* are changing for each of 45 buildings over time, as other variables describing insulation measures or subsidies do at least for some of units over time. Therefore, no perfect linear relationship exists among the explanatory variables. For each t, we get $E\left(X\_{i},a\_{i}\right)=0$, indicating that the explanatory variables are exogenous. *Breusch- Pagan test* rejects the null hypothesis of constant variance across time-specific models. Since in practice no autocorrelation is rarely observed, we estimate the models with cluster-robust standard errors (Schmidheiny, 2014) that also helps to resolve the problem of heteroskedasticity and autocorrelation in all models.

Results

The effect of insulation project on energy consumption normalised per floor area per year and adjusted for weather conditions (SECA) is analysed in absolute terms (in GJ) as well as in relative terms (%) estimating following two models

$$SECA\_{it}=α\_{1}+β\_{1}PROJECT\_{it}+a\_{i}+u\_{it}$$

The coefficient $\hat{α}\_{1}$ shows an average SECA without project (dummy PROJECT=0), including the average effect of individual-specific intercepts (unobserved effects) on *SECA* (Wooldridge, 2012). Coefficient $\hat{β}\_{1}$ is statistically significant at 1% significance level. Thermal insulation (*PROJECT=1)* is associated with approximately 0.135 GJ/m2 decrease of *SECA* per year.[[2]](#footnote-2) In relative terms, PROJECT results in energy savings by 35%. Further, controlling for time trend in insulation affect (measured by years after the insulation), we do not find any substantial effect of learning or depreciation, with only small effect of time after the insulation on energy consumption at 0.001 GJ/ m2 per year. Detailed inspection indicates some learning, as people saved about 0.130 GJ/m2 during the first year of the insulation, and then another 0.010 GJ/m2 in the second year after the insulation, while in the third year the coefficient on dummy variable is small and negative (0.003 GJ/ m2), but not significant.

Next model examines the effect of insulation introduced in different time (2007-2009 then dummy *P2009* equals to 1, or after 2012 then *P2012*=1):

$SECA\_{it}=α\_{1}+β\_{1}PROJECT\_{it}+β\_{2}PROJECT×P2009\_{it}+β\_{3}PROJECT×P2012\_{it}+a\_{i}+u\_{it}$

The coefficient $\hat{β}\_{1}$ corresponds to the effect of insulation on *SECA, while t*he coefficients $\hat{β}\_{2}$ and $\hat{β}\_{3}$ are additional effects on insulation considering the period when the insulation was made. We *a priori* hypothesized the effect $(\hat{β}\_{1}+\hat{β}\_{2})$ to be smaller than ($\hat{β}\_{1}+\hat{β}\_{3})$, assuming the effects of autonomous technology improvement over time. Early investment (in 2007-2009) did not result in different effect than the insulations made during 2010-2011 (p-value = 0.45), but the coefficient for the latter interaction is significant at 5% significance level and negative, indicating that the insulation projects that were realized since 2012 on led to about one third lower energy savings than the projects implemented before 2012.

Next, we analyse the effect on energy consumption per one million CZK invested in insulation after controlling for other factors (observed as well as unobserved):

$$SECA\_{it}=α\_{1}+β\_{1}Inv6+a\_{i}+u\_{it}$$

The coefficient $\hat{β}\_{1}$ is negative and highly significant and it implies that each million of CZK invested in insulation of the apartment building resulted in energy savings at the magnitude of about 0.01 GJ/m2 per year (model 5). Considering the average heated floor area – that is 3,628 m2 – we get average energy savings of 36.28 GJ per year as the effect of each million invested in the insulation project in the multi-family apartment buildings.

As the average investment in the insulation project in our sample equals to about 8.2 million CZK, it implies the average effect of about 297 GJ per year of energy saved per project. Assuming the average price of heating at 593.6 CZK per GJ, it also implies that each project on average leads to financial savings of about 176,299 CZK per year. This magnitude of financial savings can be also translated in around 46 years of payoff period.

Some of the multi-family buildings received a public subsidy and we hypothesized that the buildings that received such a subsidy could invest more into more expensive but also more efficient energy saving insulation-measures (measured by energy savings per unit invested costs). The opposite may also happened; the upward effect of subsidy may be a result of inefficient decision on investment as a part of the investment costs are subsidized by government grant. We use several models to examine this effect. Specifically, we analyse the effect of providing subsidy by introducing a dummy (model 5b) or money amount in millions CZK (model 5c), controlling for possibility to use soft loans (by subsidised interest rates, dummy SubsidyIR in model 5d), or for the proportion of subsidy on total investment (=0 if no subsidy provided, model 6).

In fact, we find very strong effect of subsidy on energy savings (model 5b). Investment in a thermal insulation resulted in savings of about 0.0102 GJ/m2 per year and per million of CZK, whereas each million of CZK of subsidy contributed additionally by 0.0016 GJ/m2 per year, resulting in overall effect of subsidized project of about 0.0118 GJ/m2 per year and per million CZK (model 5c). The effect of subsidy amount disappears if we also control for subsidizing the loans through lower interest rates, such as provided by Panel or New Panel program (model 5d). However, it turns now the effect of soft loans on energy consumption is significant and negative, approximately 0.089 GJ/m2 per year. It implies that the government programmes provided a support through lower interest rates are more effective to reduce energy than other public programs to reduce energy. 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.

Last model (6) analyse the effect of each percentage of subsidy on total investment costs. We suppose the higher proportion of subsidized investment, the lower energy savings will be as the lower subsidy may lead to stronger engagement in the insulation. We find the coefficient on *Share1* is positive and significant, yielding that each percentage of support on investment reduces the effect of insulation on energy savings by 0.0041 GJ/m2 per year (energy consumption is hence increased). However, this coefficient is not significant at any conventional level.

Table – Descriptive statistics of the dwellings, n=45.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **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 |

Figure 1. Energy consumption before and after insulation

Figure 2.- Three year average of SECA before and after the insulation for each dwelling

|  |  |
| --- | --- |
| 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 H0 (p > 0.05) | fails to reject H0 (p > 0.05) |
| \* p < 0.1, \*\* p < 0.05, \*\*\* p < 0.01 |

|  |  |  |
| --- | --- | --- |
| 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 H0 (p < 0.05)  |

|  |
| --- |
| Dependent variable: SECA |
| Independent variables | Model 5 | Model 5b | Model 5c | Model 5d | Model 6 |
| 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 H0 (p > 0.05) | reject H0 (p < 0.05) | fails to reject H0 (p > 0.05) | reject H0 (p < 0.05) | fails to reject H0 (p > 0.05) |
| \* p < 0.1, \*\* p < 0.05, \*\*\* p < 0.01 |

1. The first, online approach showed to be inefficient since the response rate was very low (8 out of 200 sent emails were received back with response). 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) 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 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. Altogether the data we have obtained from each source forms 18 %, 27 % and 55 %, consecutively. [↑](#footnote-ref-1)
2. 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 *ai*, 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. [↑](#footnote-ref-2)