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Effectiveness of Residential Buildings Renovation on the Example of Kaunas City

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Abstract. Improvement of energy efficiency in buildings is one of the main strategic goals of country's energy strategy and its' implementation policy. This goal is being implemented using support measures and implementation instruments in public and residential buildings. Implementation programs were designed and are being implemented in this sector since year 2004; however, there is still lack of research investigating the effectiveness of implemented actions in terms of environmental, economic, and social sustainability using respective criteria. On the other hand, there is lack of objective information for wider research based on measured data, as most of the data comes from programs administrators as estimated energy consumption and savings. The paper provides main criteria for defining renovation sustainability of multi-apartment residential buildings as well as initial assessment of energy efficiency improvement in such buildings implemented under programs partly funded by EU funds and Modernization program for multi-apartment houses. The Kaunas district heating company provided data of metering readings for 103 buildings which are fully or partially renovated in Kaunas City and Kaunas Regional municipalities and covers period of 12 years. The results of investigation show wide scattering of renovation effectiveness regarding renovation costs, energy savings and costs of saved energy.

Keywords: residential buildings, assessment criteria, renovation effectiveness.

Conference topic: Energy for Buildings.

Introduction

Improvement of energy efficiency in buildings is one of the main options for implementation of sustainable energy. Buildings sector is the sector responsible for significant share of energy consumption and has the highest potential in energy efficiency's improvement via renovation of obsolete buildings stock. Revised National Energy Efficiency Action Plan (NEEAP 2014) shows that the energy saved in residential buildings sector was 6.87 ktoe in 2010, and the other 47.97 ktoe should be saved by 2016. Savings were estimated using *bottom-up* approach. This target should be achieved conducting several measures, such as Renovation Programme for Multi-apartment Residential Houses (2005–2020), Promotion of Modernization of Multi-apartment Buildings measure using EU Structural Funds (2007–2013) and others, thus achieving 1000 GWh energy savings in buildings by 2020. However, nobody investigates sustainability of the energy efficiency improvement activity, based on above defined measures, as currently used criterions for a measure sustainability assessment are CO_2 emissions reduction and (primary) energy saving. The insufficiency of this is clearly seen via assessment of implemented measures. Most criteria, including multi-criteria approach are used for sustainable energy planning and not for monitoring and assessment of implemented measures, whether those were measured.

EU requirements have strong influence on member-states policies. This concerns also the sustainable energy development, including improvement of energy efficiency (EE) actions in final consumption. This is defined in EU Energy efficiency directive 2012/27/EU, Energy performance of buildings directive 2010/31/EU, etc., the aim of which is improvement of the efficiency via the effective use of energy resources. Implementing of European Energy and Climate policy towards mitigation of human activity influences climate change.

Problem formulation

Potential impacts that could be assessed evaluating the improvement of energy efficiency include:

– *Economic:* employment (job creation), income, food production, rural electrification and stability in supply, terms of trade, energy intensity and cost impacts in industry, buildings, and transportation;
– *Social*: urban and rural development, literacy, health impacts, education, innovation;
– *Environmental: climate resiliency;* air, soil, and water quality, water use, biodiversity, GHG emissions.

Criteria

Several assessment criteria were selected for assessment of the effectiveness of building renovation process. Selection was strongly restricted by the availability of data, which could be used for assessment. Besides, bearing in mind that criteria selected were to be clear and measurable, enabling comparison of various buildings, no matter what type of building and what renovation technologies were applied. Such criteria have to be easily understandable. Besides, they must be sound and reflecting the main energy, environmental and social targets of EU energy policy.

After assessment of available data, as well as evaluating the fact that there are no objective data for assessment of the effectiveness of implemented support measures, institutions providing support are guided by estimated values, we suggest to use the following criteria for assessment the effectiveness of energy efficiency improvement measures in building sector (Steinhilber *et al.* 2011):

– Effectiveness of support measures

$$\mathrm{E_n} = \frac{Q_{n-1} - Q_n}{POT_{n-1}}, \tag{1}$$

where: Q_n – energy savings, *POT* – saving potential.

– Costs of saved energy (Martinaitis *et al.* 2004)

$$\mathrm{SEK} = \frac{I \times CRF}{DE}, \tag{2}$$

where: *I* – investment; $CRF=d/(1-(1+d)^{-t})$ – investment return factor, *d* – discount rate, *t* – life-time of energy saving measure, *DE* – energy savings per year.

– Costs of avoided emissions

$$\mathrm{IEK} = \frac{I \times CRF}{IE_{CO2ekv}}, \tag{3}$$

where: $IE_{CO2ekv}=DE \times k_{CO2kuro} \times f_{pe}$ – avoided emissions per year, f_{pe} – fuel primary energy factor.

Available data

Saved annual energy volume per square meter of residential area is the main effectiveness criterion of renovation process as energy efficiency improvement measure. However, data for estimate of this criterion is not as easily available as could be expected. Data before renovation as well as after it, available for public are just estimate and not actual measured. Such measured data could be available in data bases of district heating companies. On the other hand, comfort level indicators, such as inside temperature, relative moisture content and CO2 concentration, even fresh air flow is not investigated. Audits are not obligatory on adequacy of microclimate conditions to hygienic regulations neither before nor after renovation. Certain conclusions can be gained from residents of the buildings or Investment projects; however, they still cannot be considered as reliable data. The importance of above mentioned microclimate parameters for assessment of building renovation effectiveness can be seen from research of Lithuanian scientists (Ankėnas, Motuzienė 2015; Stasytė, Martinaitis 2015). The only obligatory action at least partly investigating the effectiveness of building renovation is energy certification of the building; however, it discloses the effectiveness of renovation process just in case it is performed before and after renovation. Obligatory upgrading of ventilation systems, balancing of heating systems and automatic regulation appeared in the new Renovation (modernization) programme (RMPMH 2013) and this was not applied in former renovations. Therefore, residents used to deal with such problems as lack of fresh air flow, increased moisture inside premises and respectively mould forming, need for forced ventilation.

Regarding proper assessment of the renovation quality, one needs not only perform certification of the buildings but also energy audit before renovation and after. Audits should assess the quality of building envelope, heating and ventilating systems, as well as microclimate parameters.

Information on energy consumption data in specific residential houses is nearly not available, unless residents are storing their bills for heating and hot water from DH Company before and after renovation.

AB "Kauno energija" is one of the few district heating companies which provides monthly meter's readings in their website since January 1, 2011. It also provides data on building heating system and substations managers. For the purpose of this investigation our research group was kindly provided with measured heat consumption data for 103 renovated multiapartment residential houses in Kaunas City and Kaunas Regional municipalities. The data contains the address, heated area, heat assigned to hot water system, heat for heating of premises, total heat volume and annual heat consumption for space heating per square meter for the period of full 12 years (2004–2015). However, there was no data on the type of renovation, implemented energy saving measures, therefore, in some cases the renovation can be simple change of substation or replacement of outside doors and windows.

The measured heat consumption data for space heating was normalised using actual annual degree days at internal temperature 18 °C (estimated using calculator of Energy Agency (www.ena.lt)) and standard heating season degree days for Kaunas region and limiting outside temperature of 10 °C – 3789 degree days according to the construction norm RSN 156-94 (Fig. 1). There was no indication on the year of renovation in the data set.

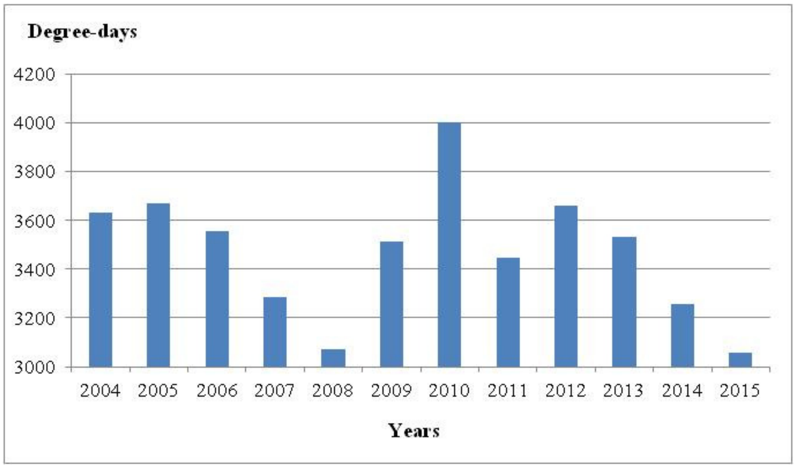

Fig. 1. Actual degree-days of period 2004–2015 for Kaunas region

Pre-screening of the data was made excluding from analysis the data where renovation year was not evident, i.e. there was no visible effect seen from the data on heat demand for space heating. After pre-screening 80 buildings were chosen for deeper analysis.

Distribution of total heated area in all buildings by building size is shown in Figure 2. The largest share of area is in big houses, which is typical feature of building stock of most towns with developed multi-apartment living areas.

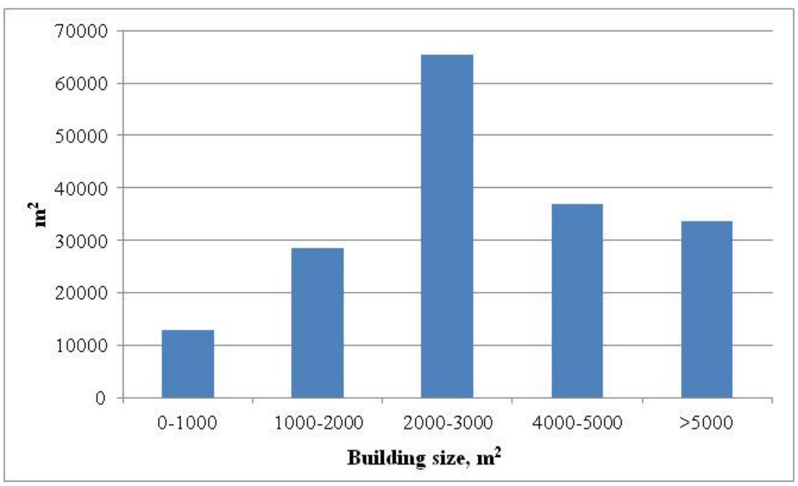

Fig. 2. Distribution of heated area among different building sizes, m^2

Effectiveness of energy efficiency measures in residential buildings

The total normalized heat demand evolution for the investigated building group is provided in the Figure 3 below where we can see gradual diminishing of heat demand for space heating resulted from more efficient heat consumption with increased share of renovated buildings. An average heat demand per square unit of building heated area decreased from 144 to 97 kWh/m^2.

Despite the fact that all investigated buildings are in different parts of the Kaunas City and some of them are connected to small local DH systems, we can assume all the buildings as being in one DH system. Based on analysed heat demand data in renovated buildings the heat supplier can forecast future network load and required heat generation capacity for future needs provided all buildings in the network undergo renovation. The question is how precise the renovated buildings reflect the real building stock in existing system. Thus, judging from Figure 4, the total heat demand in renovated buildings decreased from 37 to 25 GWh per year or by 32%. On the other hand, heat demand for hot water hasn't changed significantly. This means that rehabilitation of hot water preparing systems in buildings does not add much to total energy performance of the building.

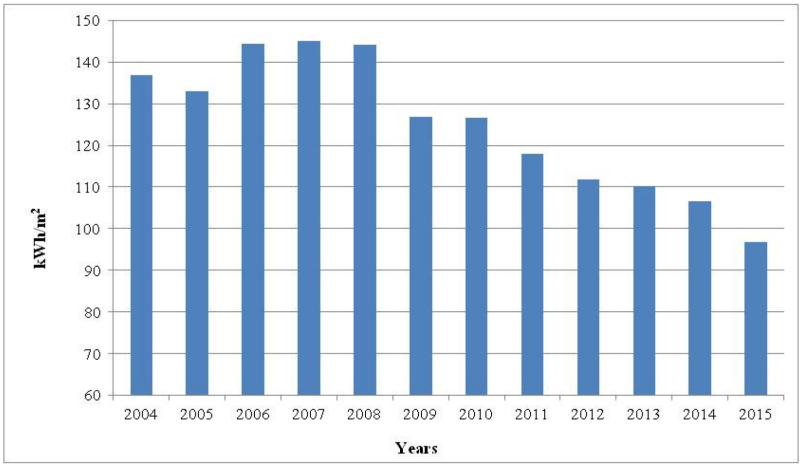

Fig. 3. Changes in heat demand for space heating during investigated period

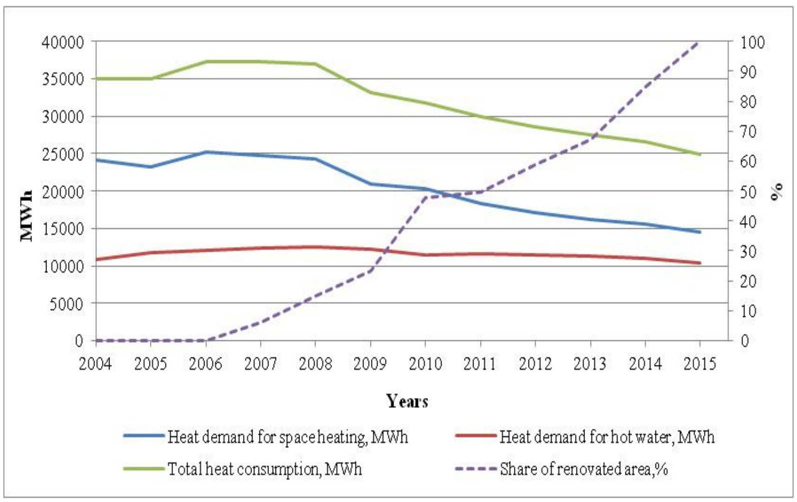

Fig. 4. Changes of heat demand in MWh and share of renovated area in percent during investigated period

The data on heat consumption for space heating were distinguished in two sets of data: before and after renovation for more evident renovation effect. However, as there are no exact dates from which we should account consumed heat as "after" renovation, there is some intermittent period considered as renovation process. There can be data included of the year of renovation, where data of first half of the year (January–April) contain metering readings of not renovated building and rest of the year contain data of already renovated building, as renovation of the building usually takes place during summer season when no heating is required. In rear cases building renovation can be performed in several steps and in different years. Such data rearrangement clearly shows cumulative renovation effect for all building stock and even provides some information on building performance after renovation (Fig. 5). Thus, some increase of heat demand can be seen after 2–3 years which can be explained by customers' need for better comfort after they recognize that the cost for additional couple of degrees of inside temperature, opposite to not renovated building, is not so large and is affordable. Nevertheless, above conclusion must be regarded critically, as most data cover only 1–3 – year period after renovation. Longer time perspective is needed to prove or reject above consideration.

Further investigation was directed towards calculation of social and environmental criteria and attempts were made to find out possible correlations of building size, initial heat demand and invested money with the result of renovation e.g. energy savings. Heat supplier has no information on renovation costs, therefore respective investments were found from different sources, mainly from the Housing Energy Efficiency Agency providing support for renovation projects. Total number of buildings with known investments was 47. Further analysis was made for these buildings.

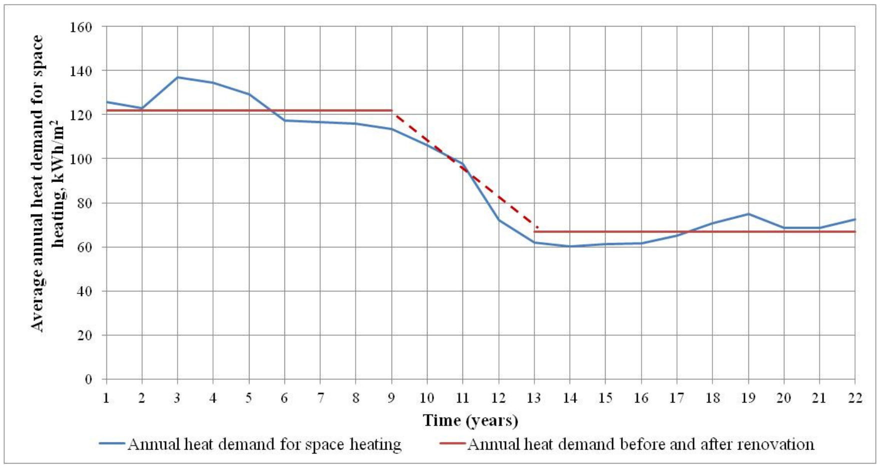

Fig. 5. Cumulative effect of renovation on specific heat demand for space heating

It is known fact that relative heat demand is bigger in smaller buildings. This also can be seen from the data in Figure 6, where relative heat demand before and after renovation is presented. In this case correlation between heat demand and building area is evident and remain of the same character after renovation.

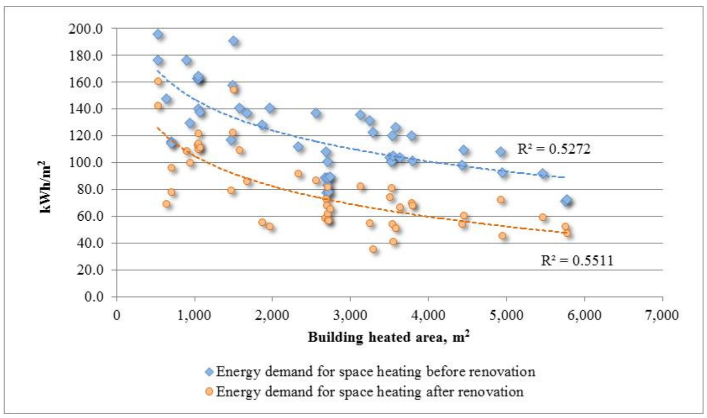

Fig. 6. Relative heat demand versus building heated area before and after renovation

Figure 7 presents data on energy savings for space heating versus total building heated area. One can see that there is no correlation between building area and energy savings. Moreover, in big houses exceeding 4000 m^2 energy savings per unit of heated area is even less than for those in small and mid – size houses.

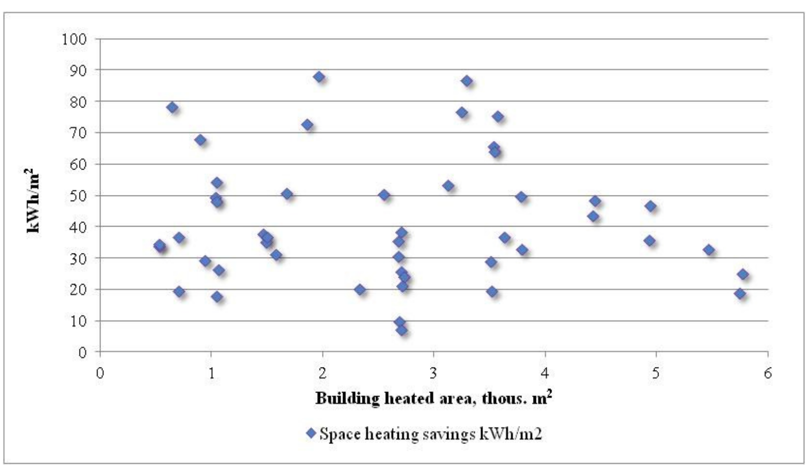

Fig. 7. Energy savings for space heating versus building heated area

Another factor considered as influencing renovation efficiency is building energy performance before renovation also can be tied with the quality of building insulation. Logically there is a big variety of possibilities for energy performance improvement in non-efficient building. Nevertheless, as can be seen from Figure 8, the data shows weak correlation between energy savings and heat demand before renovation and no correlation is observed in case heat savings are expressed as percentage from heat demand before renovation (Fig. 9).

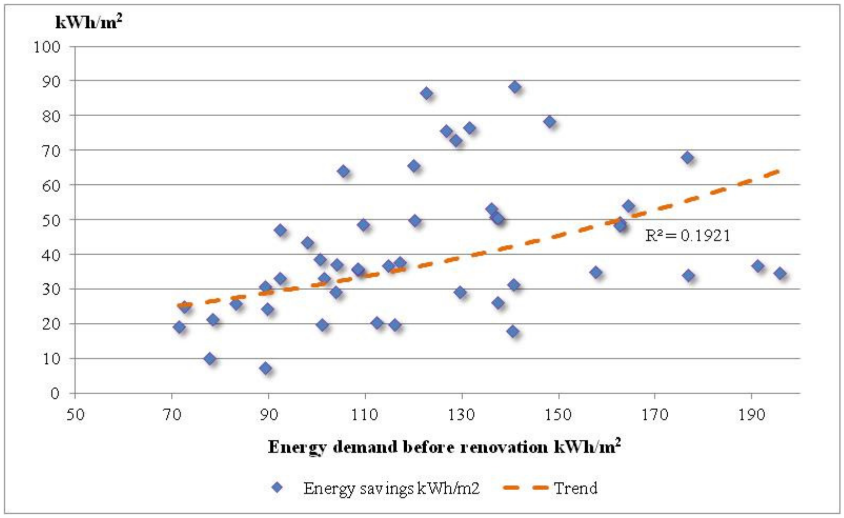

Fig. 8. Energy savings versus heat consumption before renovation

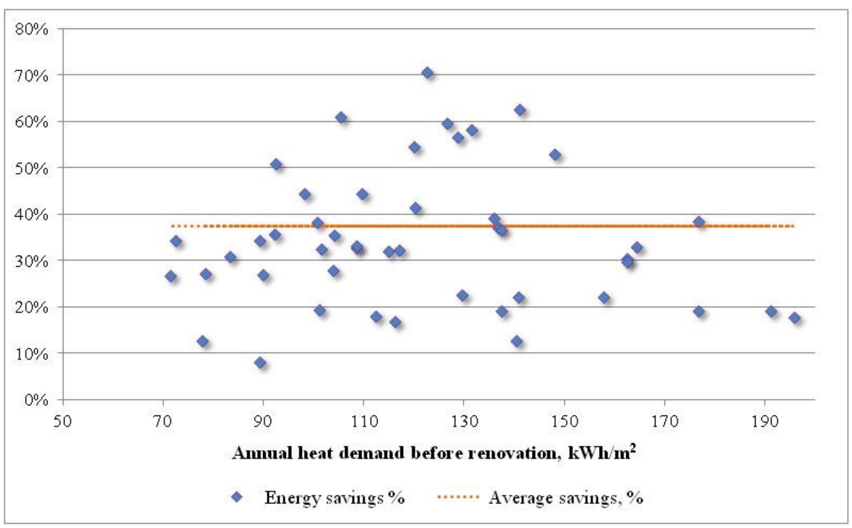

Fig. 9. Energy savings in percent versus heat consumption before renovation

Significant influence on renovation quality was expected from the amount of investment. It is logical that relative investment per square meter for smaller buildings is higher than in big buildings. This can be explained by bigger outside surface which requires insulating per square of heated area and higher construction site costs. Despite widely scattered amount of investment which can be as low as 10 €/m^2 and as high as 300 €/m^2, the data presented in Figure 10 generally proves this relationship, however, there is no correlation between saved energy and investment.

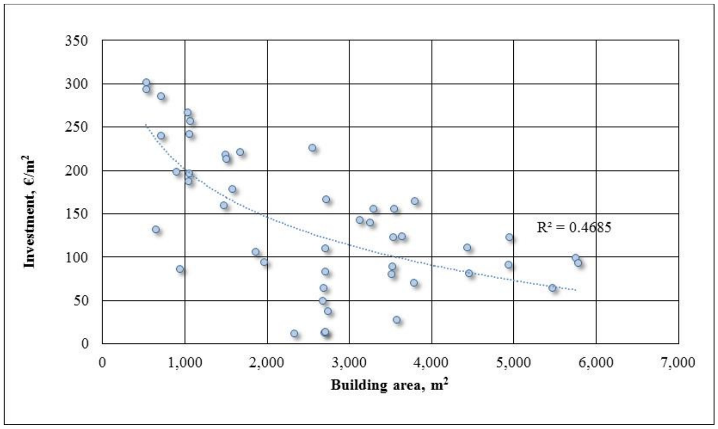

Fig. 10. Relative investment into energy saving measures versus building heated area

Economic effect of building renovation for flat owners can be expressed by cost of saved energy (see Eq. (2)). 20-year life time and capital recovery factor equal to 1 was used for all investments in assessment for simplicity. It should be emphasised that the cost of saved energy in most cases is higher than heat price which varies each month depending on fuel price and average price in year 2016 was 56 €/MWh (Fig. 11). Higher relative investment needed in smaller houses results in higher cost of saved energy.

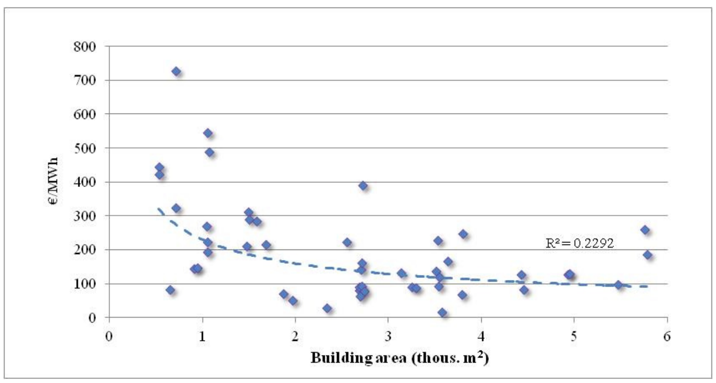

Fig. 11. Cost of saved energy versus building area

Environmental effect of building renovation is expressed per cost of saved CO_2 emissions (see Eq. (3)). Since there is no possibility to define CO_2 emissions conversion factor for specific building, we have assumed the one recommended by Methodology for Assessment of Green-House Gases Emissions Reduction for district heating, which is 0.233 tCO_2 per MWh (MAGHGER 2012) (Fig. 12).

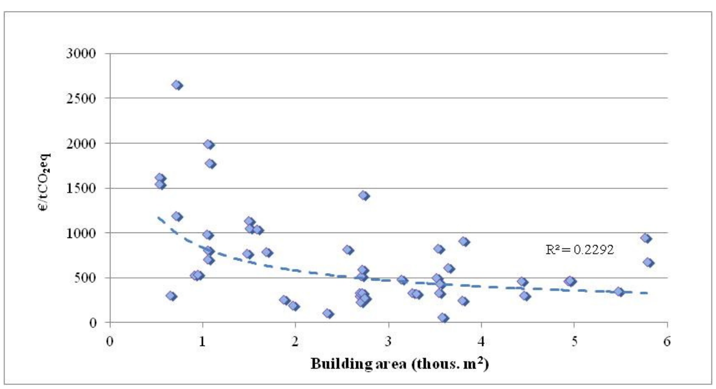

Fig. 12. Cost of saved CO_2 emissions versus building area

An analysis of available data containing meter readings from 80 renovated buildings in 12-year period from 2004 to 2015 allowed general conclusions on average values of the renovation process (Table 1).

Table 1. General figures of building renovation

Indicator	Units	Value
Average investment	€/m^2	114.7
Average savings	kWh/m^2	41.0
Average cost of saved energy	€/kWh	0.140
Average percentage savings	kWh/m^2	35.7%
Average cost of avoided CO_2 emissions	€/tCO_{2eq}	510

Conclusions

For proper assessment of the renovation quality one needs not only perform certification of the buildings but also energy audit before renovation and after. Audits should assess the quality of building envelope, heating and ventilating systems, as well as microclimate parameters.

Total actual measured heat demand in renovated buildings decreased by 32% only. On the other hand, rehabilitation of hot water preparing systems in buildings does not add much to total energy performance of the building.

Energy savings for space heating versus total building heated area shows that there is no correlation between building area and relative energy savings. Moreover, in big houses exceeding 4000 m^2 energy savings per unit of heated area might be even less than for those in small and mid size houses.

Though it is expected that a big variety of possibilities for energy performance improvement should exist in non-efficient buildings, nevertheless, there is a weak correlation between energy savings and heat demand before renovation and no correlation is observed in case heat savings are expressed as percentage from heat demand before renovation.

Despite widely scattered amount of investment between 10 €/m^2 and 300 €/m^2, and expectation that relative investment per square meter for smaller buildings is higher than in big buildings, the data assessed proves this relationship, however, there is no correlation between saved energy and investment.

Economic effect discloses that the cost of saved energy in most cases is higher than heat price, and higher relative investment needed in smaller houses result higher cost of saved energy.

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Disclosure statement

Authors of this article do not have any competing financial, professional, or personal interests from other parties.

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