Improving the indoor climate and energy saving in renovated apartment buildings in Estonia

Anti Hamburg[1*] and Targo Kalamees[1]

[1] Tallinn University of Technology, Ehitajate tee 5, 19086 Tallinn, Estonia
anti@tktk.ee

Abstract. Energy saving is one of the driving forces in renovation of buildings. Ideally, energy savings should cover the cost of renovation. For purposes of cost efficiency, energy use before and after renovation should be known as accurately as possible. If the energy saving target is too ambitious, energy use after renovation could increase notably and, vice versa, if the target is too low, renovation may not be feasible.

In this study we analyze how well the energy saving targets are achieved in renovated apartment buildings in Estonia. The analysis is based on measurements and simulations of indoor climate and energy use in 20 comprehensively renovated apartment buildings. A professional designer and consultant have made an energy audit and design solution before the renovation. Our task was to check the energy audit and compare target and real energy use.

We found out that in most cases energy auditors have not assessed existing structures and ventilation correctly, and that basic energy audits should be more detailed in order to assess the existing buildings' energy consumption. Energy saving targets after renovation were also overoptimistic. Based on our research the Estonian energy renovation grant scheme was upgraded.

Keywords: energy saving, energy audit, renovation, apartment buildings.

1 Introduction

Energy use in buildings is the largest segment of energy use. Although the requirements for energy use of new buildings have been tightened since the energy crisis in 1970s, the energy use of existing buildings is still high [1] compared to what we expect from today's new buildings and from future near-zero energy buildings. Because the replacement rate of the existing building stock is only some percentages per year, the renovation and improvement of energy performance of existing building stock plays an important role in reaching national energy efficiency targets. Depending on the Member State, only 0.4-1.2% of the building stock is renovated each year [2]. Baek [3] showed that lack of awareness, information, and regulatory system as well economic reasons are the major barriers to improving the energy performance of existing residential buildings. Kuusk [4] showed that the apartment associations' investment capability is not sufficient to achieve the energy efficiency level of new buildings or low-energy buildings and subsides will increase investments of apartment associations into energy efficiency improvements.

Many studies have shown that investments in energy performance and comprehensive renovation of existing apartment buildings would be economically viable in longer terms [5–10]. In reality the cost effectiveness depends on how accurately energy saving targets are achieved. Branco et al. [11] showed after a 3-year experimental study that the real annual energy use was 268.3 kWh/m^2 instead of initially predicted 44.4 kWh/m^2 because the theoretical value does not take into account real conditions. Cali et al. [12] evaluated refurbished German dwellings and showed the average energy performance gap variation between 41% to 117% during different years. Majcen [13] analyzed Dutch social housing stock, renovated between 2010 and 2013, and showed that the energy performance gap is lower in more efficient buildings.

In Estonia the majority of the multistore apartment buildings were built during the period from 1960 to 1990, employing similar construction solutions. The priority of this dwelling programme was to build as quickly as possible and energy efficiency was not considered important during that period. Systematic renovation of residential buildings started in 2000s when also the energy performance regulation entered into force. During the period between 2010 and 2014 a total of 663 apartment buildings were renovated under the renovation grant scheme and supported by Ministry of Economic Affairs and Communications fund Kredex. To receive finance support, 3 levels for thermal energy saving were established (30, 40 and 50%). The government grant was 15, 25, or 35% from total cost, respectively. The total investment of apartment associations and the grant scheme amounted to 151 million euros, of which 38 million was in form of grants. In this study we analyze how the indoor climate and energy saving improved in these renovated apartment buildings.

2 Methods

In our case study we had analyzed 20 apartment building with different building types (CE: Prefabricated concrete element, AAC: lightweight concrete, Brick) and renovation solutions (Table 1). The heating system was renovated in all buildings. Renovation of ventilation system varied from system cleaning to installing fresh air inlets (FAI) or installation of a completely new ventilation system (SERU: supply-exhaust room units, EXHP: exhaust ventilation with heat pump heat recovery, AHU: central air handling unit).

Energy consumption data before and after reconstruction was collected by building managers. Energy balance contains use of electricity (including household electricity), heating and domestic hot water (DHW). We checked all energy audits made by consultants using the same method. In addition to the original energy balance, we separated energy for production and circulation of DHW. Because apartment buildings with district heating have only one heating meter that measures energy for room heating and DHW we calculated energy for DHW based on water use (DHW is 45% from whole water usage) and temperature rise (50 °C). This calculation based on measured values

[16]. The circulation heat loss is calculated based on difference of theoretical and measured energy use for DHW during summer months.
We measured indoor temperature, ventilation airflow and CO_2 concentration in all buildings in order to compare thermal energy use with the indoor climate situation. The table (see **Table 1**) shows building codes involved in government financial support. 15 means 15% financial support and 30% heating energy saving, 25 means 25% support and 40% heating energy saving and 35 means 35% support and 50% heating energy saving.

Table 1. Studied renovated buildings.

Code	Building type	Constr. year	Heating area (m^2)	Floors	Renovation works and additional insulation			
					Ex. wall	Roof	Windows	Vent
15.1	Brick	1970	3163	5	10cm			
15.2	CE	1973	1718	4	15-20cm		Partly	FAI
15.3	CE	1969	2959	5		23cm	-	
15.4	ACC	1984	1737	3	15cm	20cm	Partly	FAI
15.5	CE	1976	3075	5				
25.1	ACC	1975	777	2	15cm	25cm		FAI
25.2	Brick	1982	2623	5	15cmm	25cm		FAI
25.3	CE	1988	3519	5	15cm	20cm	Partly	FAI
25.4	Brick	1975	550	2	15cmm	25cm	Partly	
25.5	Brick	1971	1903	2	10-15cm	30cm	Partly	FAI
35.1	Brick	1978	1064	3	12cm	13cm	Partly	SERU
35.2	ACC	1979	1285	3	15cm	13cm	Partly	SERU
35.3	Brick/ACC	1982	1527	4	15cm	25cm	Partly	EXHP
35.4	Brick/ACC	1979	1041	3	15cm	23cm	Partly	EXHP
35.5	Brick/ACC	1979	1162	3	10cm	23cm	Partly	EXHP
35.6	Brick	1991	1151	5	15cm	8cm	Partly	EXHP
35.7	Brick/ACC	1972	1026	3	5-15cm	23cm	Partly	SERU
35.8	CE	1970	5030	9	15cm	23cm	Partly	EXHP
35.9	ACC	1981	940	2	15-20cm	20cm	Partly	SERU
35.10	Brick	1971	561	2	15cm	10cm		AHU

3 Results

Our check showed that there are various methodological errors in existing energy audits. That's why we decided to make new calculations for all existing buildings based on measured energy data by using the same methodology. Fig. 1 (left) shows the adjusted energy consumption in the pre-renovation situation. The graph shows energy consumption for heating, DHW, DHW circulation and electrical lighting and equipment. A comparison of adjusted energy consumption with auditor's values shows that the adjusted values are of the same magnitude or lower. Higher energy consumption in the pre-renovation situation (calculated by the auditor) also allows improved energy savings (Fig. 2). The main reasons why the energy consumption calculated by the auditor differed from our adjusted values are:

- Energy use that depends on outdoor temperature (heating, ventilation) must be based on the reference year. However, in some energy audits also the consumption of DHW was based on the reference year, although it does not depend on outdoor temperature.
- In some energy audits, the electricity consumption on heating, DHW, lighting and appliances was wrongly allocated. In some cases, the consumptions was calculated twice.
- Some audits had no electricity consumption at all and the auditor had for analysis used the estimated amount of energy for electricity.

When comparing the energy consumption before and after renovation (Fig. 1), we see that average energy saving in buildings is 37%. Energy consumption after renovation from total energy was in first group (energy saving target 30%, financial support 15%) in average 22%, in the second group it was 44 % (energy saving target 40%, financial support 25%), and in the last group it was 40% (energy saving target 50%, financial support 35%). When we compare total energy consumption after renovation the best results were shown by comprehensively renovated buildings with 35% financial support. In these buildings average delivered energy consumption per heated area is 119 kWh/(m^{2}· a). After renovation, in the buildings with 15% financial support it is in average 165 kWh/(m^{2}·a) which is more than 25% bigger than in comprehensively renovated buildings.

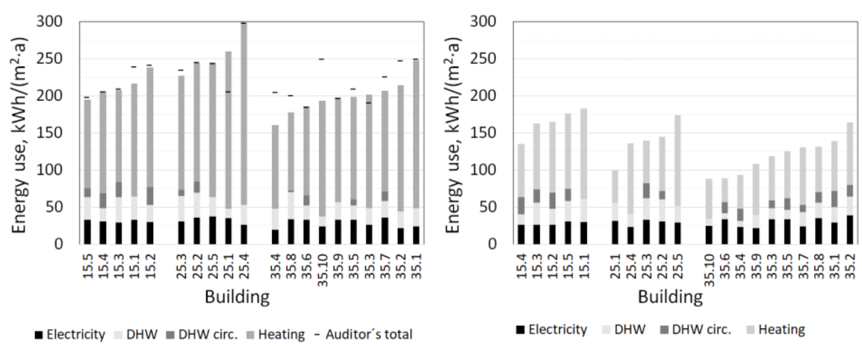

Fig. 1. Energy use before (left) and after (right).

The renovation grant scheme for buildings depends directly on energy savings achieved (heating, DHW). When comparing energy saving for room heating, DHW and DHW circulation, only half of the buildings fulfil the support criterion (Fig. 2). The reason why many buildings fail to meet the criterion is due to the differences in the calculation of energy saving. Energy use for 9 buildings (1.3; 1.5; 1.2; 2.2; 2.4; 3.8; 3.3; 3.7 and 3.10) was calculated correctly as required for the grant.

For the rest of the buildings, savings are calculated only on the heat energy used for space heating. For buildings where thermal heat consumption was calculated solely on the basis of thermal energy required for heating and ventilation air heating, the achievable energy savings (round dots) is below the level of thermal energy required under the financing requirements of the grant (Fig. 2).

In Fig.2, the round dots indicate the energy saving projected by the auditor and square dots indicate real savings. One of the reasons why the target savings were not achieved is related to errors in the calculation of thermal energy use before the renovation.

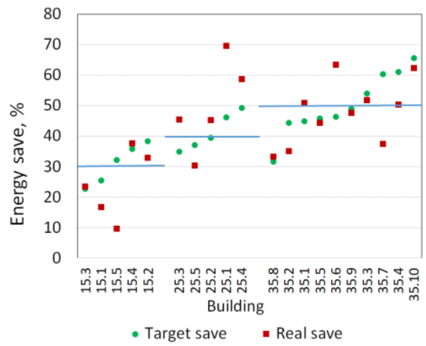

Fig. 2. Target and measured energy save compared with financial support target level (line).

Another reason why the target and real energy savings vary may be due to the difference between the calculated and actual temperature and different ventilation airflow. When analyzing indoor air temperature and ventilated airflow after renovation, we can see that they do not correlate with achievable energy savings (Fig. 3). Most buildings have higher temperatures than in the calculations and airflow is in average twice lower than the required level (0.35 l/(s·m^2)). Only some buildings (35.2, 35.3, and 35.4) where indoor air temperature is near 22 degrees and airflow per heated area is 0.2 l/s·m^2 can reach the target energy saving with energy efficiency by the fifth energy saving criterion. When we compare the target and real energy savings of various buildings with air temperature and airflow, then in buildings 15.1, 15.5, 25.5, and 35.7 there is no explicit correlation between the measured values. Therefore, we can say that the calculation of the thermal energy savings made by the auditor of these buildings was too optimistic. Looking at the energy savings achieved and comparing them with the measured airflow and indoor temperatures, we can say that in buildings 25.2, 25.4, 35.3, 35.5, 35.6, 35.7, 35.9, and 35.10 the thermal energy savings were achieved at the expense of indoor climate quality. If the airflow of these buildings is at the required level, achieving energy efficiency would be difficult (Fig. 3 right, Fig. 2). In buildings 35.3 and 35.5 the achievement of energy efficiency may be related to the low efficiency of the exhaust air heat pump and in buildings 35.7 and 35.9 with the low efficiency of space-based ventilation equipment.

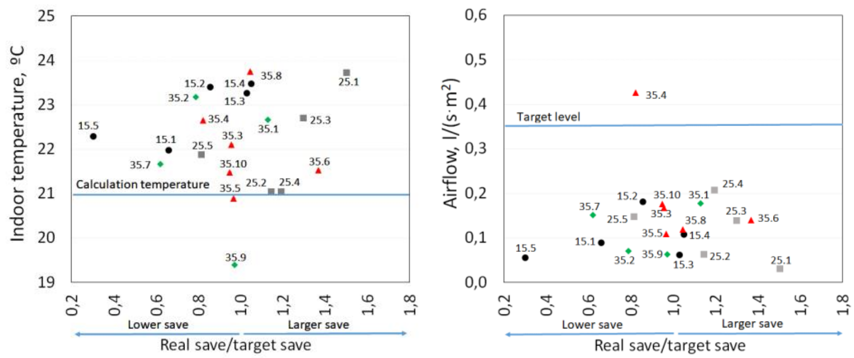

Fig. 3. The comparison of indoor temperature (left) and ventilation airflow with target energy saving for space heating (right).

4 Discussion

Half of the studied buildings achieved the target thermal energy savings. In several buildings, the real energy savings are higher than calculated. This is due to the lower ventilation airflow in buildings. This result is distressful, because energy savings cannot be achieved at the expense of worse indoor climate. The airflow was at the required level only in one building. As a result of our study, we can say that it is not possible to ensure proper airflow with natural ventilation. Of ventilation equipment, also room-based ventilation equipment proved problematic (noise, draft, efficiency, etc.). Therefore we no longer recommend to use these units for renovation of residential buildings in cold climate. That has been shown also by Simson [17].

We found a number of calculation errors in energy audits. Most of the errors were related to the reduction of heat energy use to the reference year and wrong allocation of electricity use for heating, DHW, lighting and appliances. In some cases, the energy auditor had also taken twice into account some energy use. This shows that there is a need for a common method of energy auditing. Better control would help to avoid such mistakes. In the future, there should be trained consultants who could check the most common errors.

There is no requirement to separate hot water circulation from domestic hot water supply in Estonian energy efficiency regulation. Heat losses from hot water circulation was a problem in houses that had a local electric boiler but after renovation are using district heating (35.2; 35.3; 35.4). In those buildings domestic hot water circulation losses after renovation were about 10 kWh/(m^2·a) and DHW and DHW circulation was after renovation that much bigger. This shows us that we also need a calculation method for hot water circulation.

In four apartment buildings (15.1, 15.5, 25.5, and 35.7) where measured indoor temperature was comparable to calculated temperature and real airflow was more than half lower than required, it was clear that energy saving calculations made by auditors contain mistakes. It is likely that auditors showed better energy saving target in order to secure financial support. This problem showed us that thermal energy saving is not a very good base point for financial support and one possibility is to show only target heating energy consumption after renovation which is also connected with Estonian energy labeling calculations.

The second possibility why auditors' energy saving targets were too high may have been that the existing energy auditing form for calculating heat losses is too simplified. Current form enables to take into account thermal conductivity heat losses through envelopes and envelop junctions. Comparing renovated buildings' energy consumption we can also analyse other parameters which should be differently taken into account [15]. This requires updating the energy auditing methodology.

A comparison of thermal energy efficiency levels between different renovation packages shows that there is almost statistical significance ($p=0.07$) between buildings with minor renovation (target level 30% and 15% financial support) and others. This shows that minor renovation do not guarantee energy savings and it would not be feasible for the state to support it. The importance to comprehensive renovation was showed also by Kuusk [4] and Majcen [13].

5 Conclusion

The energy saving target was achieved only in 40% of buildings with minor renovations (heat saving target: 30%), 40% in buildings with average renovations (heat saving target: 40%) and 50% in building with comprehensive energy renovation (heat saving target: 50%), all together in 11 buildings.

In the course of the study we found mistakes in calculated energy consumption by auditors. There were problems in analyzing existing energy consumption data. In the future it is important to improve control to avoid such mistakes. For this we should in addition to supplementary training of auditors we also need to train consultants to detect possible mistakes in audits. This requires updating the existing energy auditing form and methodology. The majority of studied buildings had problems with ventilation, indicating that energy saving comes partly at the expense of quality of indoor climate. Therefore, it is important to find better ventilation systems that guarantee required airflow since analysed systems mostly did not enable it.

From knowledge collected from this research it is important to ensure that in the future the renovation grant scheme is no longer linked to the energy saving target but with the final energy use that is also linked with Estonian energy label calculations.

Based on our research the Estonian energy renovation grant scheme was upgraded.

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References

1. Csoknyai T, Hrabovszky-Horváth S, Georgiev Z, Jovanovic-Popovic M, Stankovic B, Villatoro O, et al. Building stock characteristics and energy performance of residential buildings in Eastern-European countries. Energy and Buildings 2016;132:39–52.
2. 2016/0381 (COD). Amending directive of the European Parliament and of the Council amending Directive 2010/31/EU on the energy performance of buildings. Brussels, 30.11.2016: European Commission; 2016.
3. Baek C, Park S. Policy measures to overcome barriers to energy renovation of existing buildings. Renewable and Sustainable Energy Reviews 2012;16:3939–47.
4. Kalle: Kuusk, K.; Kalamees, T. (2016). Retrofit cost-effectiveness: Estonian apartment buildings. Building Research & Information, 44 (8), 920−934.
5. Kurnitski, J.; Saari, A.; Kalamees, T.; Vuolle, M.; Niemelä, J.; Tark, T. (2013). Cost optimal and nearly zero energy performance requirements for buildings in Estonia. Estonian Journal of Engineering, 19 (3), 183−202.
6. Arumägi E, Kalamees T. Analysis of energy economic renovation for historic wooden apartment buildings in cold climates. Applied Energy 2014;115:540–8.
7. Niemelä T, Kosonen R, Jokisalo J. Cost-effectiveness of energy performance renovation measures in Finnish brick apartment buildings. Energy and Buildings 2017;137:60–75.
8. Ferreira M, Almeida M, Rodrigues A. Cost-optimal energy efficiency levels are the first step in achieving cost effective renovation in residential buildings with a nearly-zero energy target. Energy and Buildings 2016;133:724–37. doi:10.1016/j.enbuild.2016.10.017.
9. Saari, A; Kalamees, T; Jokisalo, J; Michelsson, R; Alanne, K; Kurnitski, J. (2012). Financial viability of energy-efficiency measures in a new detached house design in Finland. Applied Energy, 92, 76−83.
10. Bonakdar F, Dodoo A, Gustavsson L. Cost-optimum analysis of building fabric renovation in a Swedish multi-story residential building. Energy and Buildings 2014;84:662–73.
11. Rose, J.; Kuusk, K.; Thomsen, K.E.; Kalamees, T.; Mørck, O.C. (2016). The Economic Challenges of Deep Energy Renovation: Differences, Similarities, and Possible Solutions in Northern Europe—Estonia and Denmark. ASHRAE Transactions, 122 (1), 58−68.
12. Branco G, Lachal B, Gallinelli P, Weber W. Predicted versus observed heat consumption of a low energy multifamily complex in Switzerland based on long-term experimental data. Energy and Buildings 2004;36:543–55.
13. Calì D, Osterhage T, Streblow R, Müller D. Energy performance gap in refurbished German dwellings: Lesson learned from a field test. Energy and Buildings 2016;127:1146–58.
14. Majcen D, Itard L, Visscher H. Actual heating energy savings in thermally renovated Dutch dwellings. Energy Policy 2016;97:82–92.

15. Kalinic N, Krarti M. Evaluation of Measurement and Verification Procedures for Retrofit Savings Using Calibrated Energy Building Models. ASME 2010 4th International Conference on Energy Sustainability, Volume 2, ASME; 2010, p. 363–73.
16. Toode, A.; Kõiv, T.-A. (2005). Investigation of the domestic hot water consumption in apartment buildings. Proceedings of the Estonian Academy of Sciences. Engineering, 11 (3), 207−214.
17. Simson, R.; Mikola, A.; Koiv, T.-A. (2014). The Impact of Air Pressure Conditions on the Performance of Single Room Ventilation Units in Renovated Multi-storey Apartment Buildings. International Journal of Ventilation, 10 (11), 227−236