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Environmental aspects of renovations – case studies

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Abstract

In this paper we would like to show the readers two case studies of energy-, environmentally- and cost-efficient renovations of contemporary buildings in Czech Republic that were assessed according to the IEA ECBS Annex 56 methodology - elementary school Kamínky 5 (built 1987) and block-of-flats Koniklecová 4 (built 1983). Both buildings are located in Brno – Nový Lískovec. They were recently renovated into low-energy standard, with emphasis on low renovation costs and high operating cost savings. In both cases the renovation reduced energy consumption by approximately 60 %. It also improved wellbeing of the users and visual perception of the buildings.
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1. Introduction

Many developed countries are currently dealing with sustainability, reduction of overall energy and raw materials consumption (e. g. Horizon 2020 programme in EU, [1]). Large shares of raw materials and energy are consumed by building industry [2]. Therefore if any significant progress towards sustainability is to be made, it is necessary to improve the efficiency of buildings. Energy efficiency and environmentally-friendly materials are already common in new construction, but older existing buildings require attention as well. For this purpose a new methodology is developed by scientists from 11 European countries under IEA ECBS Annex 56. It focuses on optimization of renovation measures to create energy-, environmentally and cost-efficient renovations.

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To verify this new methodology, almost 20 case studies in various countries were assessed. Presented in this paper are 2 of these case studies from Brno–Nový Lískovec, Czech Rep. Elementary school located on Kamínky street no. 5 (hereafter Kamínky 5) and block-of-flats on Koniklecová street no. 4 (hereafter Koniklecová 4).

2. The original buildings

2.1. Elementary school Kamínky 5 – original state

Elementary school Kamínky 5 (see Fig. 1 – left) was built in 1987. It has approx. 380 students, 40 permanent (headmaster, teachers, clerks, cooks, janitor, etc.) and 3 - 4 temporary (teaching assistants) employees. The school itself consists of 3 blocks connected by multi-storey corridors – main block (Block A) with classrooms and offices, kitchen and cafeteria block (Block B) and gymnasium (Block C). Total net heated floor area (NHFA) of the 3 blocks is 7296 m^2.

The school was built using reinforced concrete frame (system MS-OB) and ceramic panels or aerated concrete blocks as infill. The school has flat roofs made of timber or steel trusses and reinforced concrete panels. The roof was insulated by EPS placed on a sloping layer made of gravel. Original covering and waterproofing layer of the roof was made of bituminous sheets with mineral granules. Exterior doors and windows were wooden, steel or aluminium with single or double glazing. [3]

Heat for heating and domestic hot water (DHW) is supplied by a district heating network from nearby heating plant to a heat exchanger installed in Block A. Steel, cast-iron and aluminium radiators and steel pipelines were used for heating. Mechanical ventilation was used only in kitchen, cafeteria, boiler room and some store rooms. No other HVAC systems were installed. [3]

2.2. Block-of-flats Koniklecová 4 – original state

Block-of-flats Koniklecová (see Fig. 1 – right) was built in 1983. It has 60 flats in 2 different sizes (47.63 m^2 or 70.64 m^2) on 12 floors (5 flats per floor). Total NHFA of the building is 5412 m^2.

The block-of-flats was built using reinforced concrete panels (system B 70 R/K). Panels in exterior walls included in-built layer of EPS thermal insulation. The building has cold (with ventilated air cavity) flat roof, which was originally insulated by mineral wool and covered by bituminous sheets with mineral granules. Doors and windows were wooden, steel or plastic with single or double glazing, similar to the ones installed in Kamínky 5 school.

Heating and domestic hot water (DHW) systems are supplied by the same district heating network as in case of Kamínky 5. Steel and cast iron radiators supplied via steel pipelines are used for heating. Most of the building is ventilated naturally. Old ventilation system was used only in kitchens, toilets and bathrooms. Its outlets were located on the roof. No other HVAC systems were used.

Fig. 1. Street view of both assessed buildings before the renovation: Kamínky 5 (left) and Koniklecová 4 (right). [4]

3. The renovation – construction and energy efficiency

Main reason for both renovations was the age of the buildings. Both structures and equipment were morally and technically obsolete and a renovation was inevitable. Based on energy audits Borough office Brno – Nový Lískovec decided to increase the renovation costs to create 2 shining examples of energy efficient and environmentally friendly renovations. Both buildings were renovated to low-energy standard with possible future upgrade to passive standard.

3.1. Renovation of elementary school Kamínky 5

Renovation of Kamínky 5 elementary school started during the end of June 2009 – start of the summer holidays in Czech Republic. Most of the interior-related works (replacement of windows, renovation of technical equipment) were finished before start of the next school year in September 2009. The renovation was finished in December 2010.

Most significant changes relate to the buildings' envelope. The walls were insulated using EPS, XPS or mineral wool panels 160 mm thick. The roof was insulated with additional 180 mm of EPS panels and covered by new waterproofing layer made of SBS modified bituminous sheets with mineral granules. All doors and windows in the buildings‘envelope were replaced with new ones – plastic or aluminium frames with double or triple glazing. [3]

The equipment of the building was also retrofitted. Heat exchangers supplying heat for heating and DHW were replaced as well as regulatory and measuring equipment. Most of the 288 original radiators were replaced or removed; the rest was cleansed and reinstalled after revision (currently there are 276 cast-iron radiators and 8 heating desks in the school). Most heating pipes were deemed in good conditions. Therefore they were only cleansed and insulated with PE foam. DHW pipes were cleansed and malfunctioning hot water circulation circuit was replaced. Old mechanical ventilation was completely replaced. External sunblinds were installed to improve the thermal stability of the rooms during sunny weather. [3]

Table 1. Thermal properties of the Kamínky 5 buildings‘ envelope before and after the renovation. [3]

Envelope element	U-value before renovation [$W \cdot m^{-2} \cdot K^{-1}$]	U-value after renovation [$W \cdot m^{-2} \cdot K^{-1}$]
Façade	1.06	0.2
Ceiling over non-heated spaces	0.97	0.15
Windows, doors	1.50 – 5.65	1.05 – 1.70
Roof	0.58 – 0.86	0.15 – 0.16

3.2. Renovation of block-of-flats Koniklecová 4

Renovation of this building lasted from October 2009 to August 2010. It was similar to the renovation of Kamínky 5. Most works related to building's envelope. The walls were insulated using panels of up to 200 mm of EPS, XPS or mineral wool. Ceiling over the ground floor was insulated using 140 mm EPS or mineral wool panels. The roof was insulated using two layers of EPS panels, each 120 mm thick. Also new waterproofing/covering layer was installed made of mPVC plastic sheets. The openings leading to and from the air cavity were sealed. As in case of Kamínky 5, old wooden or metal doors and windows in the buildings‘envelope were replaced with new ones – plastic or aluminium frames with double or triple glazing.

The technical equipment was renovated too. Heat for heating and DHW is supplied by district heating. Original heat exchanger was replaced, as well as all measuring and regulation equipment connected to these systems. The heating system now has equithermal regulation. Old circulation pumps on the DHW circuit were replaced. Radiators and most of the pipelines were left in place as they were deemed to be in good condition. The ventilation system was outdated, but complete renovation would have been too expensive. Therefore central ducts were left in place and only new ventilators, noise damping and exhaust outlets were installed. The ducts connecting ventilators with the central duct were also replaced.

Table 2. Thermal properties of the Koniklecová 4 buildings' envelope before and after the renovation.

Envelope element	U-value before renovation [W·m^{-2}·K^{-1}]	U-value after renovation [W·m^{-2}·K^{-1}]
Facade	0.78 – 0.80	0.17 – 0.24
Ceiling over non-heated spaces	1.13	0.33
Windows, doors	1.20 – 5.65	1.05 – 1.70
Roof	0.50	0.15

3.3. Energy efficiency of the renovations

Improvements of thermal properties resulted in significant reduction of heating energy consumption. Savings were achieved in case of DHW, although they were less than expected. This was probably caused by the fact that parts of DHW systems (e.g. circulatory circuit in Block A, Kamínky 5) were out of order before the renovation. Electricity consumption remained the same in case of Koniklecová 4 or slightly increased in case of Kamínky 5, due to the installation of new equipment (measuring and regulation systems, etc.). Overview of achieved energy savings can be seen in Table 3 and Table 4.

Table 3. Energy consumption of Kamínky 5 elementary school before and after the renovation. [3]

Energy consumption	Before renovation [kWh·m^{-2}·a^{-1}]	After renovation [kWh·m^{-2}·a^{-1}]	Savings
Heat - heating	100.0	31.1	68.9 %
Heat – DHW	14.3	12.7	11.1 %
Electricity	3.1	3.3	-3.8 %

Table 4. Energy consumption of Koniklecová 4 block-of-flats before and after the renovation.

Energy consumption	Before renovation [kWh·m^{-2}·a^{-1}]	After renovation [kWh·m^{-2}·a^{-1}]	Savings
Heat - heating	97.2	24.9	74.4 %
Heat – DHW	32.4	25.8	20.2 %
Electricity	30,4	30.4	0.0 %


Fig. 2. Street view of both assessed buildings after the renovation: (left) Kamínky 5 elementary school, (right) Koniklecová 4 block-of-flats.

4. Environmental assessment

4.1. Used tools, data and boundary conditions

Both presented case studies were assessed according to the Annex 56 methodology. They were (as well as most other case studies in Annex 56) assessed using Swiss tool Eco-Bat, version 4.0. [5] In this paper we present results of these assessments in 3 impact categories: Global Warming potential (GWP), Non Renewable Energy (NRE) and Total primary Energy (TPE)

Data about the renovations themselves were gathered from available designs (drawings, bills of quantities, etc.) and energy audits. Data about the use of both buildings before and after the renovation (average energy consumption, repair and maintenance costs, etc.) are based on annual invoices.

Expected service life of a renovated building is 60 years. Individual structures and parts have shorter service life – between 20 (heating equipment) and 60 years (e.g. superstructure of the roof). To represent this structures and parts with shorter service life are calculated several times.

4.2. Environmental impact assessment

Two scenarios for each building are compared. First scenario includes the buildings in their original state before the renovation. In this scenario only the necessary renovations and maintenance are included, e.g. replacement of windows after the end of their service life. Second scenario includes executed low-energy renovations, regular repair and maintenance. The impact of the executed renovations can be in both cases seen in significant reductions of energy consumption (chapter 3.3). This reflects in the environmental assessment of the buildings' life cycle, as well – see Table 5 and Table 6.

Table 5. Environmental impacts of both assessed variants of Kamínky 5 elementary school.

	GWP [kg CO_2-Eq·m^{-2}·a^{-1}]	NRE [kWh·m^{-2}·a^{-1}]	TPE [kWh·m^{-2}·a^{-1}]
Original state (before renovation)	58.9	279.4	270.6
Current state (after renovation)	34.9	158.9	161.6
Difference	40.7 %	43.1 %	40.3 %

Table 6. Environmental impacts of both assessed variants of Koniklecová 4 block-of-flats.

	GWP [kg CO_2-Eq·m^{-2}·a^{-1}]	NRE [kWh·m^{-2}·a^{-1}]	TPE [kWh·m^{-2}·a^{-1}]
Original state (before renovation)	76.4	349.6	355.4
Current state (after renovation)	49.6	215.9	220.1
Difference	35.1 %	38.2 %	38.1 %

From both tables above we can see overall reduction of environmental impacts, caused by the renovations. As already mentioned before, this reduction is mostly caused by reduction of energy consumption. Charts with detailed results in GWP and TPE impact categories of Koniklecová 4 block-of-flats presented in Figure 3 confirm this. Both charts show that installation of new materials and equipment, their maintenance and repairs have minimum impact on overall results – in both categories only approx. 2 % in original state and approx. 7 % in current (renovated) state. This increase of materials' impacts is more than compensated by savings achieved during the use phase (heat consumption).

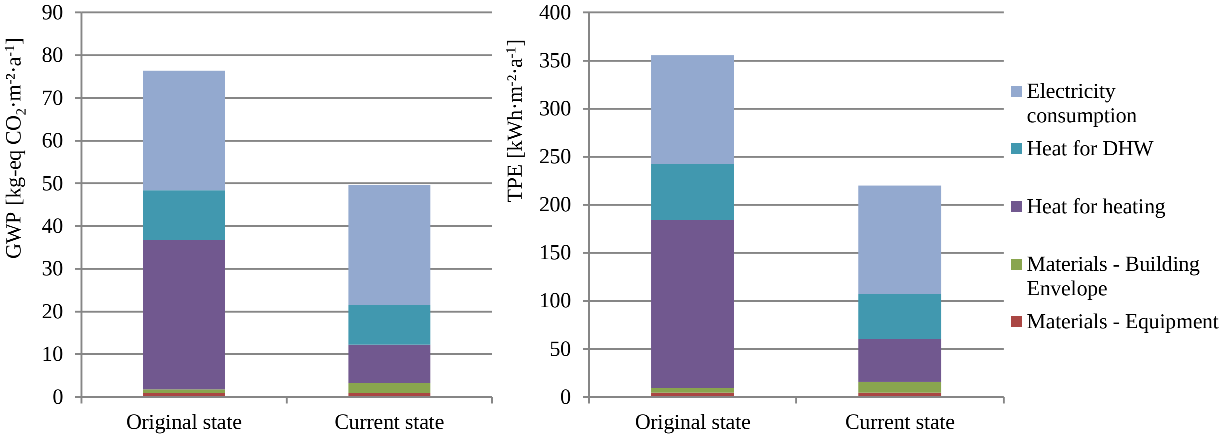

Fig. 3. GWP (left) and TPE (right) of Koniklecová 4 block-of-flats. Comparison of original and renovated building.

5. Discussion and conclusion

Most impacts (both economical and environmental) during the building's life cycle are related to energy consumption. Reducing heating energy consumption is the easiest way for improvements, but to achieve maximum savings good energy management is necessary too. Most building owners and users appreciate resulting reduction of operating costs. For example in case of Kamínky 5 the costs of energies required for operation of the building decreased from original 555.1 CZK $m\cdot^{-2}a\cdot^{-1}$ to 277.2 CZK $m\cdot^{-2}a\cdot^{-1}$ after the renovation.

Other possible improvement lies in reduction of impacts of electricity consumption of technical equipment or common appliances. But this may be quiet difficult to achieve, as we can see from both presented case studies. Modern equipment and appliances use more electricity than their older counterparts. Improving energy efficiency of the equipment may not be sufficient, because the actual number of machines and appliances in buildings still increases. If we do not want to restrict the user standards, we have to look for ways of improvements of electricity production. Impacts and prices of electricity production vary between countries [2]. Most certain (generally usable) method of improving the impacts of electricity consumption would be use of renewable energy sources on site. Currently there are many possible solutions - small water or wind turbines or photovoltaic panels, etc. But their use has various limitations, such as low efficiency and higher investment costs, fluctuations in production, temporal simultaneity of production and consumption. If the renewable energy sources are to be successfully implemented a lot of research and development has to be done. One of possible ways may be use of the renewable energy sources in scale of so called "smart cities" or "smart regions", which is a direction of authors' future research.

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