Energy use and thermal comfort of two apartment buildings before and after refurbishment in Slovakia

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Summary

This article analyzes the actual condition of building constructions, building equipment and heating system of apartment buildings. Two apartment buildings are compared; the first building is before renovation and it uses its own boiler to generate energy for heating, the second building was recently reconstructed and the energy for heating is supplied by a central heat source After the insulation of building was carried out, economic and energy savings measures were suggested in order to renovate the building and to find out probability of the same. Moreover, the residents of the two apartment buildings completed questionnaires regarding building constructions, indoor environment and ventilation behavior, and a connection was made between the energy saving measures and the subjective evaluations in order to investigate the impact of the renovation on perception of the indoor environment.

Buildings description

The investigated apartment buildings are situated in Bratislava, Slovakia. They contain flats with two and three rooms on each floor, and there are eighty flats in each building in total. The construction height of a typical floor is 2.8 metres. **Figure 1** shows the buildings before and after the refurbishment [1].

Apartment building before refurbishment

The building construction is in original condition. The walls are made of aerated concrete with the thickness of 0.3 m, which does not fulfill current technical standards on thermal insulation, because of the criteria on thermal insulation much lower in the time when the building was built. Fifty percent of windows have been replaced with energy efficient windows with plastic frames and the heat source was renovated significantly in 2009, when the building was disconnected from district heat-

Figure 1. Front sides of the two buildings: a) Before refurbishment b) After refurbishment. [1]

ing and a local heat source for heating and domestic hot water (DHW) was built in a boiler room located in the apartment building.

Apartment building after refurbishment

Energy saving measures were carried out on an identical apartment building, adjacent to the apartment building in original condition. The envelope of the building was insulated with foam polystyrene with the thickness of 0.08 m. Insulation of the roof is made of mineral wool, with the thickness of 0.05 m. All of the old windows were replaced by new energy efficient windows with a plastic frame, except for the entrance door and windows on the first floor. After renovation the U-value improved significantly and currently it satisfies the requirements on thermal protection in accordance with Slovak standards.

A significant decrease of heat loss after insulation and replacement of the windows can be seen in **Figure 2**. The specific heat loss by heat transmission (HT) decreased by 40%, while the specific heat loss by infiltration (HV) decreased by 45% after replacement of the windows, compared to the situation before refurbishment.

Table 1. Comparison of heat transfer coefficients before and after refurbishment. [1]

Construction	U-value (W/m².K) BEFORE	AFTER
Facade	0.78	0.31
Side walls	0.74	0.29
Roof	0.28	0.2
Old wooden windows	2.4	1.3
Original doors to loggias	2.4	1.5

Energy certificate

Energy certification of these two buildings was carried out in 2012 in accordance with Slovak laws and regulations. Energy need for heating was optimized after implementation of energy saving measures of the building after refurbishment. Energy need for DHW increased

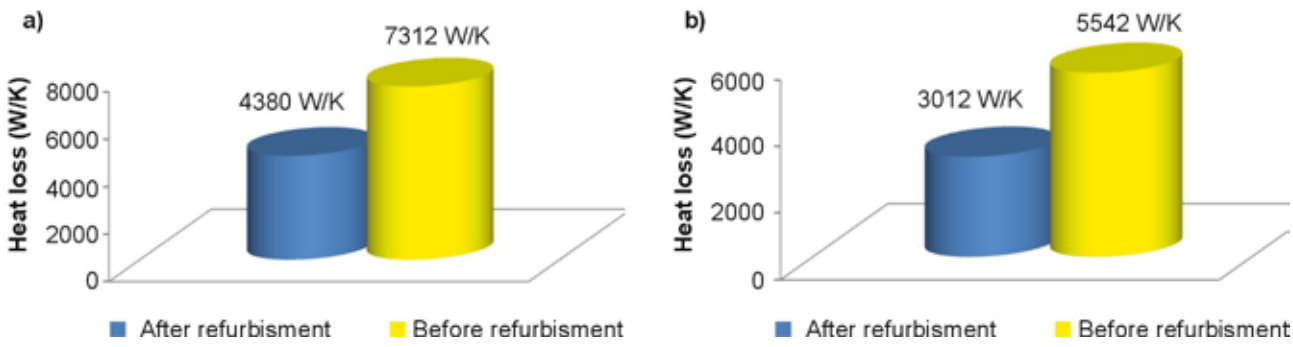

Figure 2. Comparison of specific heat loss before and after implementation of the energy saving measures. a) transmission, b) ventilation. [1]

Table 2. Energy certificate of apartment houses before and after refurbishment.

Monitored data		Building before refurbishment	Energy class	Building after refurbishment	Energy class
Heating	Energy need for heating system	597 235 kWh/a	**C**	390 992 kWh/a	**B**
	Specific energy requirement	70 kWh/m^2.a		45.6 kWh/m^2.a	
DHW	Energy use for DHW	143 960 kWh/a	**D**	143 960 kWh/a	**D**
	Specific energy needs	45 kWh/m^2.a		51 kWh/m^2.a	
	Primary energy	150 kWh/m^2.a		125 kWh/m^2.a	
	CO_2 emissions	26.45 kg/m^2.a		22.08 kg/m^2.a	
	Total energy	115 kWh/m^2	**C**	96 kWh/m^2	**C**

in the refurbished apartment building, because of insufficient insulation of the distribution pipes.

Heating energy consumption and cost

The data to compare the cost of heating are for the year 2010. Following figures compare the cost of heating in the apartment building connected to district heating with the cost of heat in the apartment building with own local heat source.

Cost of heating in the apartment buildings

The cost of heat generated in the local heat source is lower than the cost of heat generated by district heating, when the saving per GJ is up to 44% in the building with own local heat source.

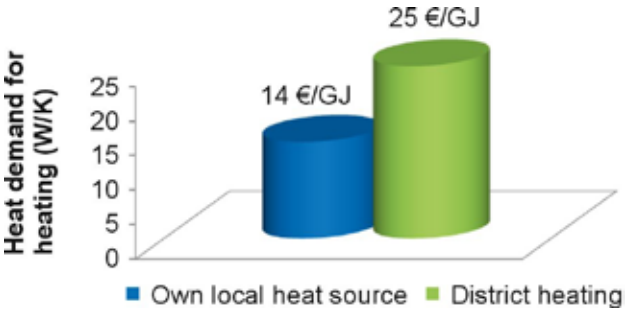

Figure 3. Cost of heating for the apartment building with own local heat source (left) and the building connected to a district heating system (right). [1]

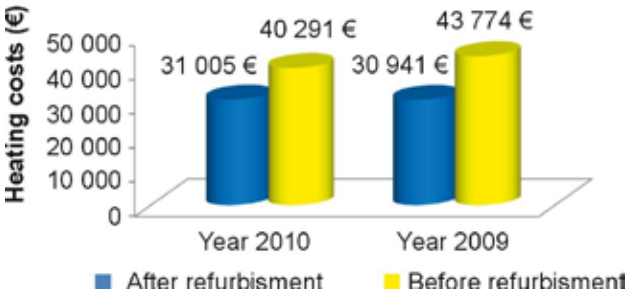

Figure 4. Comparison of heating costs for the two apartment buildings in 2009 and 2010. [1]

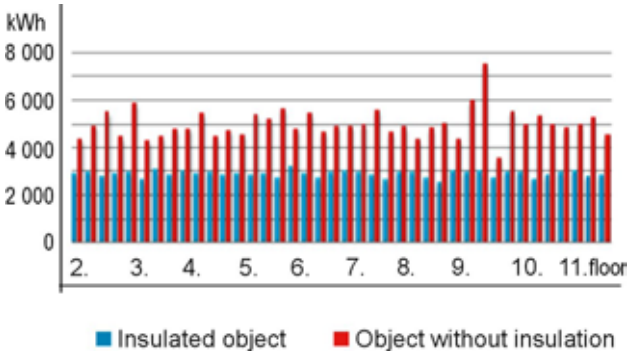

Figure 5. Comparison of measured heat consumption in flats. [1]

Analysis of energy consumption

The measured energy consumption in 2010 shows that the energy consumption of the building before refurbishment was about 28% higher than the total energy consumption of the refurbished building.

Figure 5 shows comparison of the measured energy consumptions of the buildings in 2010; the results are shown separately for each floor. The difference between the highest and the lowest heat consumption of flats was about 40% in the building before refurbishment, causing dissatisfaction between residents of the building. On the other hand, the highest difference in heating costs was only 12% in the apartment building after refurbishment with the insulated facade and roof.

Energy monitoring

After implementation of an energy saving project it is often found that the energy consumption has increased one or two years after refurbishment. Energy

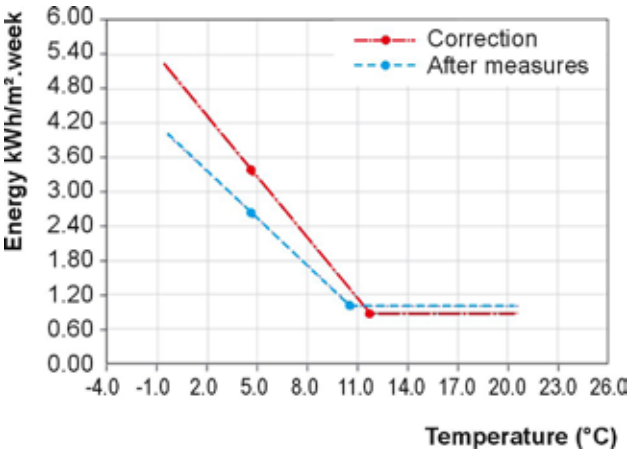

Figure 6. ET-curve of the two apartment buildings. [1]

monitoring is a management tool to keep the energy consumption at low level and to prevent the energy consumption increase after the refurbishment. It is based on a regular readout of the energy meters. In the present case the energy monitoring was performed by the Ensi EAB 8.1 software, developed in Norway. The energy consumption depending on mean daily outdoor temperature (or eventually it can be also mean weekly outside temperature if the readout is done on weekly basis) is graphically represented by the ET-curve (Energy-thermal curve). The energy consumption for heating in **Figure 6** is represented by the sloped line, whereas the horizontal line represents the energy consumption for DHW, which does not depend on the outside temperature. **Figure 6** shows that the calculated weakly consumption dropped from 5.19 kWh/(m².week) to 4.00 kWh/(m².week) in the insulated building, at the mean daily outside temperature of 0°C. The hot water consumption is higher in the refurbished building, because of the insulation of horizontal pipes being too old and damaged (insulation of DHW distribution pipes was not part of the refurbishment).

Table 3. Evaluation of thermal sensation and thermal comfort.

Indicator	Before refurbishment	After refurbishment
PMV index	0.74	0.92
PPD index	16.57%	22.88%
Perception of temperature	0.14	0.52

Thermal comfort

In order to achieve comfort of the occupants in the enclosed environment, it is necessary to fulfill several requirements at the same time. A questionnaire survey was performed by the occupants of the buildings, containing questions regarding various aspects of their indoor environment to allow complex assessment of their satisfaction with their living environment.

The questionnaire survey

The questionnaires used to evaluate the indoor environment and the condition of building constructions consisted of four main parts, containing questions regarding building constructions, indoor environment, natural ventilation and basic information about occupants. The questionnaire survey was conducted in January 2012 and was completed during working days in the period from 04.00 pm to 07.30 pm [2].

Thermal comfort

Evaluation of thermal comfort was carried out using the seven-point thermal sensation scale, as defined in EN15251 and EN ISO 7730. The results are shown in **Table 3**.

Typical clothing ensembles of the inhabitants at home

Figure 7 shows that the greater part of men and women prefer moderately warm clothing in apartment building

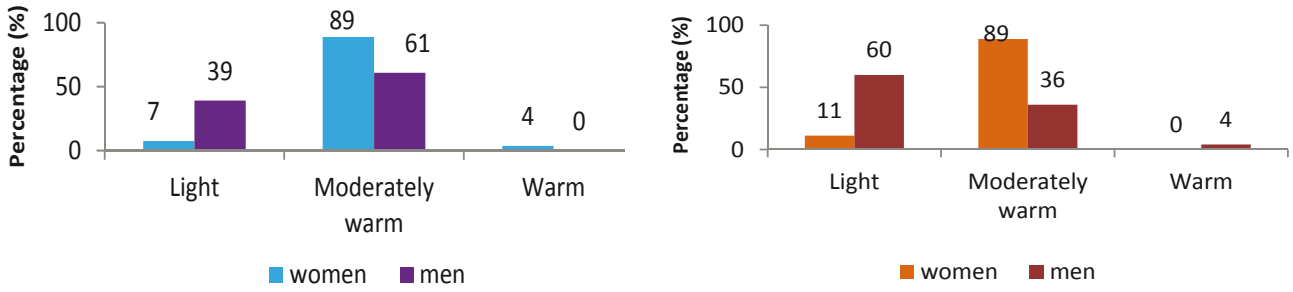

Figure 7. Typical clothing ensembles of residents in the apartment buildings.
a) Before refurbishment. b) After refurbishment. [2]

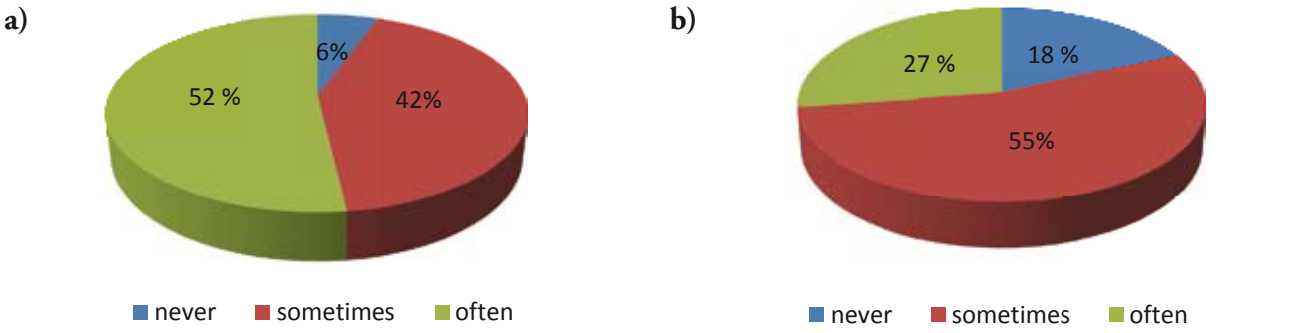

Figure 8. Utilization of temperature settings in apartment buildings: a) Before refurbishment b) After refurbishment. [2]

before refurbishment. Majority of women prefer moderately warm clothing and greater part of men prefer light clothing in apartment building after refurbishment.

Temperature settings in the apartment buildings

In both apartment buildings the inhabitants have the possibility to set the air temperature in each apartment. The following charts show how often people adjust the temperature in their apartments.

Conclusion

The energy need for heating system in the apartment building after refurbishment can be classified into a better energy class. Residents of the refurbished apartment building perceived the thermal conditions in the building as more acceptable than residents of the apartment building before refurbishment. The present study indicated that refurbishment of a building can contribute to the improvement of the indoor environment, however, it must be planned and implemented with care, otherwise it might affect the indoor environment adversely.

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