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Effect of refurbishment on thermal comfort and energy use in residential multifamily building

The article presents a case study performed on a multifamily residential building situated in Slovakia. The building is a typical representative of the old panel houses built in era of the massive prefabrication in Slovakia. The objective of the study was to clarify the relationship between energy consumption, energy efficiency measures and the indoor environment.

The evaluation of the thermal comfort in apartments was carried out by means of a questionnaire distributed to the inhabitants. At the same time energy audit was performed to find out the causes of high energy consumption and identify the energy saving potential. Based on information obtained from an energy audit, the building model was constructed in simulation program IDA ICE. The real (measured) energy consumption was obtained from the administrator of the building. Through these simulations of the building a profiles of the heat balance and air temperature were determined, which depend on different conditions. Results were compared with subjective evaluation. The results show how the measures taken to reduce the energy consumption may influence the thermal comfort of indoor environment.

Hana Pustayová
Slovak University of Technology in Bratislava,
Faculty of Civil Engineering, Slovakia
e-mail: hana.pustayova@gmail.com

Dušan Petráš
Professor
Slovak University of Technology in Bratislava,
Faculty of Civil Engineering, Slovakia

Residential buildings in Slovakia

The situation in the housing sector in Slovakia has been changing seriously during last 15 years. According to the Housing census, held in 2008, in the Slovak Republic there were 5 412 254 inhabitants. Total housing stock amounted to 1 988 000 of which 1 768 000 permanently inhabited. It means that there were 367 dwellings, respectively about 327 inhabited dwellings per 1 000 inhabitants (Ministry of Construction and Regional Development in Slovakia, 2011). The new housing production has decreased considerably in comparison with years before 1990. The production was highest in 1970's, when mainly panel buildings constructed of pre-fabricated, pre-stressed concrete were built.

Poor insulation and inadequate heating systems must be addressed given the constant increase in energy costs. The lack of funds adds to the challenge. In addition, the population expects better housing conditions. In 2006, a survey indicated that more than 50% of the population was unsatisfied with their housing situation.

We can conclude dwelling houses were constructed using almost only one technology in many decades. Consequently, the number of different structural systems is restricted. This fact can be an advantage for the refurbishment of buildings in Slovakia.

Evaluation of energy use and thermal environment

Because every building is unique, each project must be treated separately to find individual energy efficient possibilities. An energy audit was performed as a first step to reveal actual energy efficiency potential of building. This process consisted of building inspection, evaluation and analysis of the existing situation and various energy efficient measures that could be implemented in order to reduce the energy consumption (Dahlsveen and Petráš, 2005).

The values of real measured energy consumption were obtained from the administrator of the building.

Simulations were performed in the IDA Indoor Climate and Energy (IDA ICE), which is a tool for simulation of thermal comfort, indoor air quality and energy consumption in buildings.

For the purpose of subjective evaluation a questionnaire was created and completed by inhabitants of the building. Each questionnaire consisted of number of questions which were divided into four main parts:

- Basic information about respondent
- Building constructions
- Thermal comfort (general thermal comfort and local thermal discomfort)
- Ventilation habits

The evaluation of thermal environment was performed using PMV and PPD indices.

The PMV index predicts the mean value of the thermal votes of a large group of people, on the 7-point thermal sensation scale, exposed to the same environment.

The PPD index establishes a quantitative prediction of the number of thermally dissatisfied people. The PPD predicts the percentage of a large group of people likely to feel too warm or cool, i.e. voting hot (+3), warm (+2), cool (–2) or cold (–3) on the 7-point thermal sensation scale (CEN CR 1752).

For subjective evaluation of thermal comfort acceptability scale was used. This scale is continuous and is divided into two parts - from clearly unacceptable (–1) to just unacceptable (–0.01) and from just acceptable (+0.01) to clearly acceptable (+1).

When the PMV value has been determined, the PPD can be determined from the equation:

$$PPD = 100 - 95 \cdot e^{-(0.03353 PMV^4 + 0.2179 PMV^2)} \quad (1)$$

Case building

The building is situated in Bratislava, Slovakia and was built in 1987. The building consists of 9 floors and 1 underground garage. On the 1st floor there are entrances and common premises serving mainly as storage spaces, 2nd to 9th floor form the residential part (**Figure 1**).

a)

b)

Figure 1. Front side (south facade) of the building.
a) before renovation, b) after renovation.

External walls are made of porous concrete panels, 300 mm thick. During the renovation the building was insulated with polystyrene (thickness 80 mm) which was added to the building on the outside of the facade. The flat roof was considered to possess insufficient thermal insulation; therefore the thickness of insulation was also increased during renovation. Original windows in common premises are constructed with wooden frames and double glazing. All of them have been replaced by plastic windows with significantly improved heat transfer coefficient than prior to renovation. The entrance of building was also renovated. Floors are without insulation, except the floor above the unheated 1st floor.

Heat and DHW is supplied from a heat exchange station connected to the building. The piping is led through the wall of the building. The main branch is led under the ceiling of the 1st floor from which other branches are rising to the residential part, and are led in shafts. The main branch was insulated, unlike the distribution parts led in shafts, which are without any kind of insulation. After renovation the thermal insulation from main branch was replaced for a more recent type possessing increased insulation properties. Heat in the residential apartments is emitted by means of radiators. During the renovation most of the old control valves, have been replaced by thermostatic valves with manual regulation. As the last step the heating system was hydraulically balanced.

Energy use and thermal environment before and after renovation

Since the start of renovation energy consumption of the building has been decreasing year by year as the energy efficient measures have been implemented. In 2007, thermal insulation of the facade, thermal insulation of the roof and replacement of all windows took place. In 2008 the heating system was balanced and old valves in apartments were replaced by thermostatic valves with manual regulation. In 2009, complete renovation of the building was finished. By implementing energy efficient measures the energy performance has been improved by 45%. Energy consumption was also simulated in programme IDA ICE4 as presented in **Table 1**.

Further on the **Figure 2** show the monthly energy use of typical floor of the building. Heating season in Bratislava where the building location is from October to April.

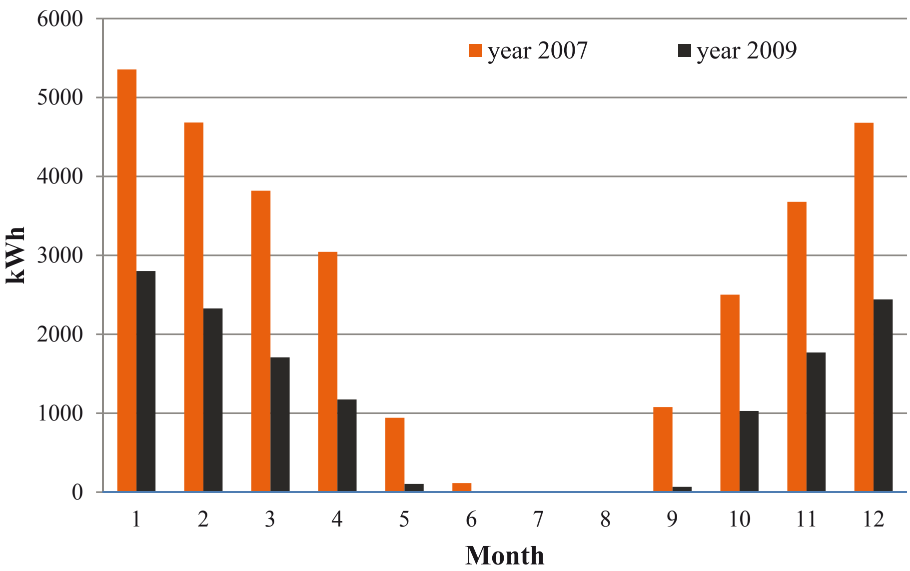

Figure 2. Monthly energy use for heating of typical floor of the building before and after the renovation.

Table 1. Annual heating energy consumption of the whole building in 2007 and 2009.

Year	Energy consumption* measured [kWh]	Energy consumption* simulated [kWh]
2007	248 472	239 192
2009	93 095	107 344

The simulation program also provides the fluctuation of indoor temperature during the year as shown in figures below. Although considerable amount of energy was saved, the range of simulation temperature of building was not substantial changed. This fact approved, that building in original condition was in bad physical condition and had inappropriate thermal protection, which caused escape supplied heat from the building.

During the heating season the indoor air temperature was 99% of time in the range of 21 – 25°C which is the specification of the category I for living spaces in the standard EN 15 251.

The subjective evaluation of the indoor environment was carried out in years 2007 and 2009. The personal questionnaires were completed by representatives of 75 percent of the residents of the apartments. Questionnaires were completed two times: before and after the renovation. For the results to be comparable, surveys were carried out in approximately the same season i.e. the middle of heating season. General thermal sensation of the inhabitants was indicated by a tick on the 7-point scale and perception of the temperature was tick on acceptability scale. **Figure 3** presents the responses of thermal sensation and inhabitant's perceived temperature in their apartments: before renovation and after complex renovation.

In the questionnaires people were asked also to mark the thermal environment they would be satisfied with. Inhabitants preferred thermal sensation between slightly warm and warm, PMV presents value 1.45. It is a

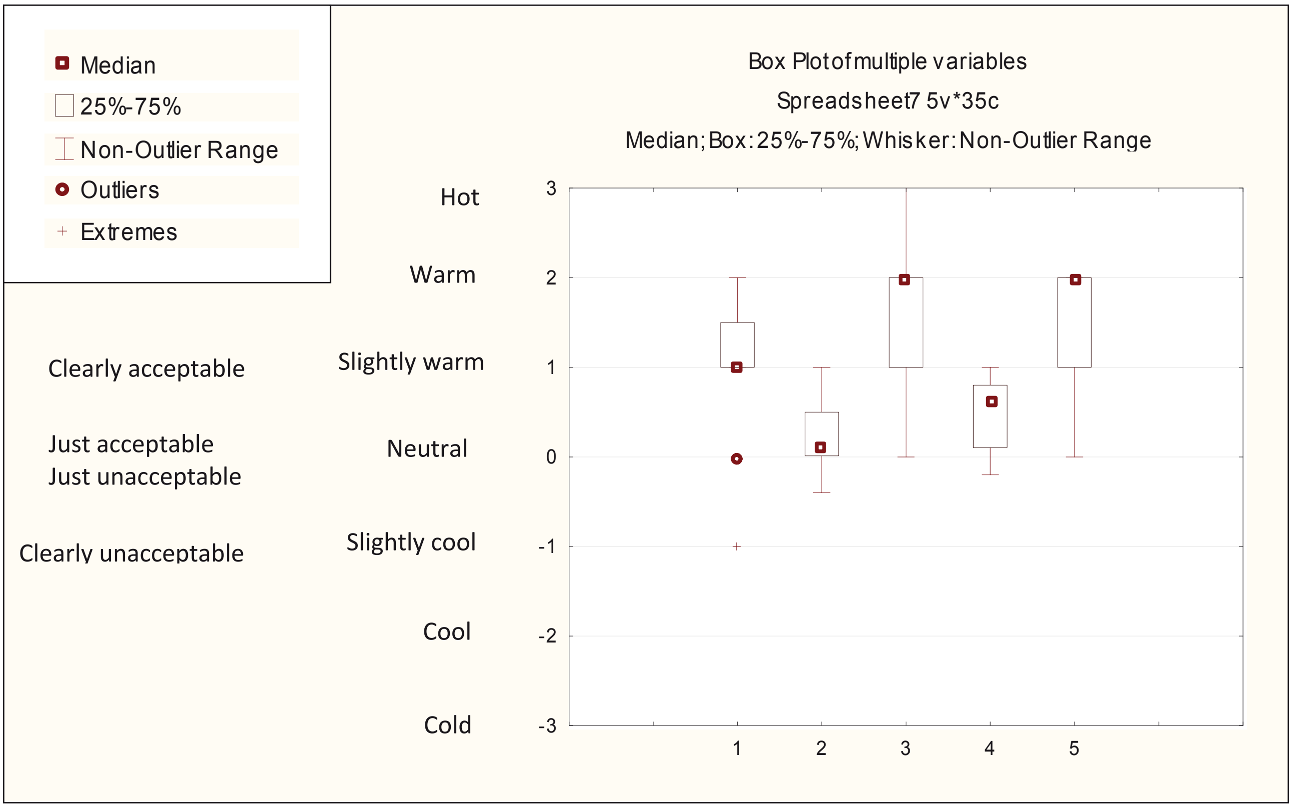

Figure 3. Evaluation of thermal sensation in apartments during whole period of refurbishment.

1- Thermal sensation –before renovation,
2- Thermal acceptability before renovation,
3- Thermal sensation –after renovation,
4- Thermal acceptability after renovation,
5- Ideal thermal sensation for occupants in the building

good indicator for comparison of inhabitant's perception during the survey. **Table 2** also shows results of subjective evaluation using PMV and PPD indices, in each year.

Conclusions

This study focuses on the relationship between energy consumption and thermal comfort. Although the complex renovation of residential building can clearly contribute to improvement of indoor environment, without thorough planning and implementation it may influence the indoor environment in an undesirable way. In order to keep the energy consumption on the desired low level, we should ensure correct operation and maintenance of the building. This case study also shows that occupant behavior influences energy consumption. It is very important to educate occupant's new behavior as the difference between indoor environment before and after renovation is significant.

Table 2. Thermal sensation and acceptability of indoor environment.

	Thermal sensation	
	2007 before renovation	2009 after renovation
PMV	1,12	1,61
PPD%	31,3	56,8
	Thermal acceptability	
	0,18	0,52

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References

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