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# Effect of building renovation on energy use and indoor environment: Comparison of simulations and measurements in six apartment buildings

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**SUMMARY**
Energy performance and the indoor environmental quality (IEQ) in three naturally ventilated original and three identical but renovated residential buildings were compared using actual measurements. Although the implemented energy saving measures had the potential to improve energy performance of the dwellings, they led to poorer indoor air quality (IAQ). Additional simulations revealed that a simple intervention, such as using exhaust systems in kitchens and bathrooms and at the same time keeping doors of rooms open, may improve the IAQ in retrofitted multifamily buildings.

**PRACTICAL IMPLICATIONS**
The results advocate the need for measures to improve indoor air quality as a part of residential energy renovation projects.

**KEYWORDS**
*Retrofitting, Residential Building, Energy Performance, Indoor Air Quality, Ventilation model*

## 1 INTRODUCTION
Most of the apartment buildings in Slovakia were built from 1945 to 1992. Many of these buildings do not fulfil current requirements on energy efficiency. Energy saving measures, such as envelope insulation and tighter windows are implemented (Panayiotou et al., 2010). The impact of such energy renovation on IEQ is rarely considered. The objective of the present study was to investigate the actual measured energy use of naturally ventilated residential buildings and its relationship with IEQ.

## 2 MATERIALS/METHODS
Three pairs of buildings were investigated. One building in each pair was renovated and the other one was in its original state. Energy use for heating was monitored in all six buildings during the entire heating season and the specific heat demand was calculated according to the National Building Code (2012). IEQ parameters (see Table 1) were measured during the winter in 50% of all apartments within each building. Evening and night-time data are presented to represent occupied periods. Occupants´ satisfaction with IEQ in their apartments was investigated by using questionnaire survey. Additionally, dynamic building performance simulations were carried out using IDA-Indoor Climate and Energy software (EQUA Simulation AB, Sweden). $CO_2$ concentrations were simulated for one of the buildings before and after renovation using different alternatives of ventilation systems (no mechanical ventilation, constant volume and demand controlled ventilation).

## 3 RESULTS AND DISCUSSION
Table 1 compares the calculated specific heat demand, the measured energy performance and the measured IEQ in the original and the renovated buildings. Implementation of energy

saving measures reduced energy use for space heating by more than 30%. Although the energy performance of the buildings improved after renovation, higher $CO_2$ concentrations ($p \geq 0.05$), lower air exchange rates (AER; $p < 0.05$) and lower acceptability of air quality (ACC) ($p < 0.05$) were observed in the renovated dwellings compared to the original buildings in winter.

For one of the buildings we created simulation models of its original and renovated state. Results of the simulations confirmed that energy renovation without considering additional ventilation, which is often the common practice, may increase $CO_2$ concentrations in the apartments (Table 2). Adding standard air handling units in bedrooms, or, at the minimum, exhaust systems in kitchens and bathrooms while at the same time keeping internal doors open, may significantly improve IAQ in newly energy renovated residential buildings.

Table 1. Summary of the energy performance and night-time (20:30-6:30) averages of IEQ parameters in the original and the renovated residential buildings

| Building pairs | Building condition | Energy performance | | | | | Indoor Environmental Quality* | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Specific heat demand | | | Actual energy use for space heating | | RH | T | $CO_2$ | AER** | ACC | Thermal Sens. | Thermal Accept. |
| | | kWh/m$^2$.year | Energy class | Diff. (%) | kWh/m$^2$.year | Diff. (%) | (%) | (°C) | (ppm) | (h$^{-1}$) | (-) | (-) | (-) |
| I | Original | 136 | D | 57 | 96 | 53 | 49 | 21.4 | 1740 | 0.68 | 0.50 | 0 | 0.35 |
| | Renovated | 58 | B | | 44 | | 45 | 23.2 | 1930 | 0.44 | 0.06 | 2 | 0.30 |
| II | Original | 145 | D | 38 | 104 | 49 | 48 | 22.4 | 1320 | 0.82 | 0.49 | 1 | 0.67 |
| | Renovated | 90 | C | | 53 | | 47 | 23.1 | 1580 | 0.52 | -0.02 | 2 | 0.38 |
| III | Original | 139 | D | 48 | 101 | 39 | 48 | 21.7 | 1060 | 0.97 | 0.71 | 1 | 0.58 |
| | Renovated | 71 | B | | 62 | | 47 | 21.8 | 1520 | 0.49 | -0.04 | 2 | 0.17 |

*Each value is the grand mean obtained for all investigated apartments within the given building.
**The recommended minimum ventilation rate is 0.5 h$^{-1}$.

Table 2. Simulated night-time (20:30-6:30) averages of IEQ parameters in building pair I, and for the renovated building using various alternatives of ventilation systems

| Building condition | Alternatives of ventilation system | | | | Indoor Environmental Quality | | | |
|---|---|---|---|---|---|---|---|---|
| | Ventilation | System type | Location | Mech. air supply per year | $CO_2$ | $T_{op}$ | $T_{air}$ | RH |
| | | | | | (ppm) | (°C) | (°C) | (%) |
| Original | Natural vent | Opened windows in period 7:00-7:30 and 19:00-19:30. | Bedroom | 0 kWh | 1190 | 17.8 | 17.9 | 37 |
| Renovated | Natural vent | Opened windows in period 7:00-7:30 and 19:00-19:30. | Bedroom | 0 kWh | 1520 | 20.3 | 20.4 | 33 |
| Renovated | Air Handling Unit | Temperature and $CO_2$ control | Bedroom | 635 kWh | 800 | 20.1 | 20.1 | 25 |
| Renovated | Air Handling Unit | $CO_2$ control | Bedroom | 624 kWh | 795 | 19.9 | 19.9 | 25 |
| Renovated | Air Handling Unit | CAV Exhaust only; opened doors of room | Kitchen, bathroom | 0 kWh | 755 | 19.0 | 18.8 | 27 |

## 5 CONCLUSIONS

Envelope insulation and window replacement can decrease the energy use for heating by over 40% in multifamily dwellings in Central Europe, built mainly of concrete panels. Such basic energy renovation may however deteriorate the indoor air quality, unless at least simple measures are taken to achieve increased air exchange rates in the apartments.

## 6 REFERENCES

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