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Effect of energy renovation on indoor air quality in multifamily residential buildings in Slovakia

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A B S T R A C T

Buildings are responsible for a substantial portion of the global energy consumption. Most of the multifamily residential buildings built in the 20th century in Central and Eastern Europe do not satisfy the current requirements on energy efficiency. Nationwide measures taken to improve the energy efficiency of these buildings rarely consider their impact on the indoor air quality (IAQ). The objective of the present study was to evaluate the impact of simple energy renovation on IAQ, air exchange rates (AER) and occupant satisfaction in Slovak residential buildings. Three pairs of identical naturally ventilated multifamily residential buildings were examined. One building in each pair was newly renovated, the other was in its original condition. Temperature, relative humidity (RH) and the concentration of carbon dioxide (CO_2) were measured in 94 apartments (57%) during one week in the winter. A questionnaire related to perceived air quality, sick building syndrome symptoms and airing habits was filled by the occupants. In a companion experiment, the IAQ was investigated in 20 apartments (50%) of a single residential building before and after its renovation. In this experiment, concentrations of nitrogen dioxide (NO_2), formaldehyde and total and individual volatile organic compounds (VOC) were also measured. CO_2 concentrations were significantly higher and AERs were lower in the renovated buildings. Formaldehyde concentrations increased after renovation and were positively correlated with CO_2 and RH. Energy renovation was associated with lower occupant satisfaction with IAQ. Energy retrofitting efforts should be complemented with improved ventilation in order to avoid adverse effects on IAQ.

1. Introduction

Buildings are responsible for one third of the global energy consumption [1]. Reduction of energy consumption and greenhouse gas emissions is a national priority in the European Union member countries [1,2]. The residential sector represents a major target group for national programs supporting energy efficiency improvements of existing buildings. More than 50% of the European population resides in multifamily buildings [3].

The potential negative impact of building energy conservation measures on indoor air quality is a matter of concern. Minimizing air infiltration by tightening the building envelope is a common practice [4–9]. When unaccompanied by improved ventilation, such energy saving measures can lead to insufficient ventilation rates [10] and increased exposure of building occupants to indoor pollutants [11–13]. Residential exposure is of particular concern, as more than half of the time spent indoors takes place in residences [14]. It is therefore important to understand how energy saving strategies influence indoor air quality and the comfort and health of occupants.

Studies on the impact of energy retrofits of dwellings on IAQ are relatively limited. Improved thermal conditions and health indicators were reported after installing standard insulation in New Zealand [15]. In California, comprehensive energy retrofits combined with improved mechanical ventilation systems and air

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cleaners resulted in improved indoor environmental conditions [16]. Positive effects of energy retrofitting on indoor environmental quality and occupant satisfaction were also shown in mechanically ventilated residential buildings in Sweden [17]. Additionally, better indoor air quality in low-energy or passive houses compared to conventionally built houses has been reported in a number of studies [18–21]. Satisfactory indoor air quality in these buildings was achieved by relatively high air exchange rates provided by mechanical ventilation.

Energy saving measures started to receive increased attention in Central and Eastern Europe since the 1990's, two decades later than in Western Europe. Indoor air quality however does not receive consideration to the same extent. Adoption of new building standards with primary focus on energy conservation is feared to compromise indoor air quality. This is especially the case in the almost exclusively naturally ventilated buildings built before 1990. Very few studies have been conducted in multifamily residential buildings in Central and Eastern Europe [21–24]. Multifamily residential buildings in Slovakia were built between 1948 and 1990 and they well represent the residential building stock of Central and Eastern Europe. About 70% of these buildings do not fulfil the current European requirements for energy efficiency [25]. This has led to the implementation of numerous energy retrofit campaigns for existing multifamily buildings [3]. However, the effect of these programs on indoor air quality and occupant wellbeing is neglected.

The objectives of the present study were to evaluate in multifamily residential buildings in Slovakia the impact of energy renovation on i) temperature, relative humidity, CO_2 concentration, air exchange rates and concentrations of selected air pollutants using objective measurements, and on ii) perceived air quality and occupants' airing habits using questionnaire survey.

2. Materials and methods

2.1. Experiment I

2.1.1. Selected buildings

The first experiment included three pairs of multi-storey residential buildings made of prefabricated and pre-stressed concrete panels. Each pair consisted of a non-renovated and an identical renovated building (Table 1). The energy-retrofitting measures included thermal insulation of the façade and the roof, and hydraulic balancing of the continuously operating heating system. The façade was insulated with expanded foam polystyrene of 80 mm thickness. Mineral wool insulation of 120 mm thickness was added to the roof. The ground floor apartments in each building were situated above an unheated basement. The basement ceiling was thermally insulated with 80 mm thick expanded foam polystyrene. No changes have been made to the windows, since new plastic frame windows have been already installed by the owners in most of the apartments before the study. All buildings were naturally ventilated. Exhaust fans operated by the light switch were present in the bathrooms and toilets. No modifications were made to the ventilation systems during the renovation. All buildings were located within 1 km from each other, in the rural city of Šamorín (13.000 inhabitants), 25 km from the capital of Slovakia, Bratislava.

2.1.2. Physical measurements and questionnaire survey

The experiment was carried out between the middle of November 2013 and the end of January 2014. Ninety-four apartments were investigated in total, 45 were in the three non-renovated and 49 in the three renovated buildings. The measurements in each apartment lasted one week.

Air temperature and relative humidity were measured in the bedrooms by HOBO U12-012 data loggers (Onset Computer Corp., USA). The concentrations of CO_2 were measured with 5-min intervals by CARBOCAP CO_2 monitors (GMW22, Vaisala, Finland) connected to the HOBO data logger. All instruments were newly calibrated prior to the measurements. The locations of the instruments were selected with respect to the limitations of the CO_2 method [26]. Each unit was placed at a sufficient distance from windows and beds to minimize the influence of the incoming fresh air or the influence of sleeping occupants.

CO_2 concentrations obtained between 20:30 and 6:30 during each measured night, room volume and the occupants' body weight and height were used to calculate the AER in the bedrooms. The methodology using a spreadsheet that employed the carbon dioxide mass balance equation has been described in detail earlier [27]. Briefly, the CO_2 concentration build-up period was used to estimate the AER for each respective night in the occupants' bedrooms [26–28]. Air exchange rate in the room was estimated by fitting a non-linear curve to the measured pattern of the CO_2 concentration at a given CO_2 emission rate, room volume and outdoor CO_2 concentration. Occasionally CO_2 concentration decays were used, when CO_2 levels began to fall while the room was occupied in the evening, i.e. when the occupants indicated that they aired out. When the concentration build-up or decay could not be clearly defined, the air exchange rate was determined using a mass balance model applied on the estimated steady-state CO_2 concentration [26]. Only trustworthy fractions of the night periods with clear CO_2 concentration patterns were extracted and used for further analysis. AERs were determined separately for each night with known occupancy. The final air exchange rate for each bedroom was calculated as a time-weighted average of the air exchange rates obtained for each relevant time period.

One occupant in each apartment was asked to fill a questionnaire. The questions were related to some building characteristics, occupant behavior and habits (e.g. frequency and duration of airing), sick building syndrome symptoms and occupants' perception of the indoor air quality and thermal environment (e.g. acceptability of indoor air quality in the apartments using the

Table 1
Characteristics of the studied buildings.

Building pair	I.		II.		III.	
Building condition	Original	Renovated	Original	Renovated	Original	Renovated
Construction year	1965	1970	1970	1972	1980	1983
Major orientation	East	East	Northwest	Northwest	North	North
Height (m)	27.7	27.7	30.2	30.2	13.1	13.1
Number of floors	10	10	9	9	4	4
Number of apartments on each floor	4	4	2	2	6	6
Number of measured apartments	20	20	11	15	14	14
Volume of each apartment (m^3)	210	210	258	258	194	194
Area of each apartment (m^2)	75	75	92	92	69	69
Heating system/Heating device	District heating/Radiators with thermostatic valves					