

# Results of Indoor Air Quality Parameters Measures in Not Renovated Multi-Apartment Buildings

Ilze Dimdina, *Riga Technical University*, Eriks Kruminis, *Latvia University of Agriculture*,  
Arturs Lesinskis, *Riga Technical University*

**Abstract.** Indoor air quality (IAQ) measures within energy audit inspections in 13 not renovated multi-apartment buildings (MABs) show that CO<sub>2</sub> concentration level in 16 out of 30 examined apartments was  $\geq 1000$  ppm, indicating insufficient ventilation. The results of measures and inspections affirm the necessity to realize only complex renovation activities in existing MABs to enhance energy efficiency and indoor microclimate of buildings.

**Keywords:** indoor air quality, CO<sub>2</sub> concentration, multi-apartment buildings, renovation, natural ventilation.

## INTRODUCTION

Previous experience shows that renovation of ventilation systems is not a typical component of renovation of MABs in Latvia. The typical solution for ventilation of the existing MABs – with natural exhaust channels from the toilet facilities and kitchen premises, and air inflow through gaps between the window frame and window carcass – does not ensure return of heat from the exhaust air and cannot ensure maintenance of room microclimate that would be independent of weather conditions and would correspond to the requirements for healthy environment.

As a consequence, rooms are not ventilated enough and IAQ is reduced. This, in turn, leads to progression of the so called sick building syndrome (SBS) [1].

As the experience of other European countries concerning low-energy apartment building renovation shows (for example, Germany, East Berlin), complex renovation, including modernization of building construction insulation, heating and ventilation system etc., is the key to improving the energy efficiency of buildings and indoor climate related provision of comfort.

Renovation pilot project of MAB in Latvia, in Riga (collaboration project between the city of Riga and Berlin), confirmed advantages of complex renovation, achieving building energy efficiency improvements of 50% and better feedback from residents about the indoor climate, compared with the existing identical, but not renovated MAB [2].

The purpose of the study is to assess the natural ventilation system operation and IAQ compliance with regulatory demands for healthy environment requirements in MABs.

The study deals with building energy audits carried out under indoor air quality measurements, in particular the CO<sub>2</sub> concentration level, temperature and relative humidity measurements, natural ventilation exhaust air flow rate. Measurements of energy audits within performed with an aim to develop heat balance model of a particular building and

justify recommendations for building energy efficiency raising action plan. 12 of 13 MABs energy audits discussed were carried out before 2009, then legislation on energy performance calculation method came into force [3], based on the LR adapted with European Union standards.

Surveyed indoor climate measurements were taken in high-rise MABs, mainly built in the period from 1946 to 2000, which accounts for about 75% of the housing stock in Latvia [4]. Most of this volume consists of standard high-rise MABs, average standardized heat consumption for heating of which is 166 kWh/m<sup>2</sup> per year [5]. Theoretically, up to 60%, or ~ 100 kWh/m<sup>2</sup> from the consumption of heat energy is needed for air heating (without humidification) [6], as required by regulations [7].

## METHODS AND MATERIALS

Surveyed measurements are taken in 13 MABs, thermal characteristics of building envelope of which do not conform to current regulatory requirements for energy efficiency [8]. Apartments in the buildings are typically glazed with double windows in wooden frames ( $U \geq 2,5$  W/(m<sup>2</sup>\*K)), many of them due to depreciation in the last ~ 10 years have been changed to double glazed windows in PVC frames. New windows are mainly installed in some apartments at the initiative of the owners of individual apartments, not subjecting window thermal performance and ventilation solutions to the competent control. Typical solution for existing MABs ventilation systems is the following – using natural exhaust channels from the toilet facilities and kitchen premises (average channel aperture area 0,02 m<sup>2</sup>, ventilation louvers clean free surface area of the assessment factor 0,8), and not organized outdoor air infiltration through the leakages in the building envelope etc.

Building energy audit measurements are made using the following gauges:

- thermometer and relative humidity meter EE10-F3-D04 (working area: temperature from -5 to ~ 55 °C, accuracy +/- 0,25 °C; relative humidity from 10 to 95%, accuracy +/- 2%);
- CO<sub>2</sub> concentration level meter AQS51/61 (working area: 0 to 3000 ppm, accuracy +/- 5% of the measured value);
- air velocity meter with Testo 452 wing (working area: 0,2 to 60 m/s, accuracy 0,1 m/s);
- thermal camera Raytek Thermo View Ti 30 (working area: 0 to 250 °C, accuracy +/- 0,1 °C).

Indoor air CO<sub>2</sub> concentration level and relative humidity measurements were taken placing the detector on the floor of

the hall (buildings from A to L - legend look at chapter "Results") or 0,8 to 1,2 m above the floor in the living room (building M).

Air velocity measurements are taken by placing the detector at the natural ventilation exhaust channel ventilation louvers. The air velocity measurements at home exhaust ventilation

equipment are added to measurements in natural ventilation exhaust ducts; compiled results of measurements have not been addressed. Building envelope and the heaters surface and the outside air temperatures set was measured using a thermal camera images and data.

TABLE I  
MEASURE RESULTS IN 30 APARTMENTS IN 13 MABS

No	Mark	Type	Year	Number of apartments on each floor / total number of floors at the MAB	CO <sub>2</sub> , ppm	Relative humidity, %	Exhaust air velocity from kitchen, m/s	Exhaust air velocity from bathroom, m/s	Exhaust air velocity from toilet, m/s	Outdoor air temperature, °C
1	2	3	4	5	6	7	8	9	10	11
1	H	103	1993	1 / 5	528	31,0	0,3	0,0	0,0	-3,5
2	G	103	1993	1 / 5	677	30,0	1,3	0,4	0,4	-3,5
3	J	103	1975	1 / 6	689	<b>26,8</b>			3,0	-6,0
4	L	specpr.	1957	1 / 3	718	36,0				-6,0
5	G	103	1993	1 / 5	740	36,0	1,5	0,3	blocked	-3,5
6	M	104	1978	12/12	771	37,8				-2,2
7	C	103	1970	1 / 5	813	36,7	0,4	0,6	0,4	-2,0
8	E	specpr.	1999	/ 4	832	36,0	0,0	0,0		-5,0
9	F	specpr.	1999	4 / 4	877	41,0	0,3-0,4	0,0	0,3	-3,5
10	K	103		1 / 5	880	32,0	0,0	0,0		-6,0
11	K	103		5 / 5	900	37,1	0,0			-6,0
12	L	specpr.	1957	2 / 3	921	34,5				-6,0
13	I	specpr.	1993	/ 5	938	31,5	0,8	0,5	0,2	-5,0
14	D	103	1988	1 / 5	973	38,0		0,9		-2,0
15	J	103	1975	6 / 6	<b>1000</b>	32,0				-6,0
16	M	104	1978	4 / 12	<b>1000</b>	32,0	0,0	0,0	0,0	-2,2
17	I	specpr.	1993	/ 5	<b>1007</b>	<b>29,0</b>	0,4	0,0	0,3	-5,0
18	E	specpr.	1999	/ 4	<b>1079</b>	33,9	0,0	0,3		-5,0
19	F	specpr.	1999	4 / 4	<b>1093</b>	48,6	0,9-1,0	0,4	0,4	-3,5
20	B	602	1984	9 / 9	<b>1096</b>	30,4	0,2	0,5	0,5	-2,0
21	H	103	1993	5 / 5	<b>1110</b>	46,0	0,0	0,0	0,0	-3,5
22	I	specpr.	1993	/ 5	<b>1116</b>	30,6	0,6	0,5	0,3	-5,0
23	A	467	1974	1 / 9	<b>1216</b>	39,2	0,5	blocked		-2,0
24	I	specpr.	1993	5 / 9	<b>1250</b>	35,6	0,0	0,2	0,0	-5,0
25	G	103	1993	5 / 5	<b>1261</b>	38,0		0,3-0,8	blocked	-3,5
26	A	467	1974	9 / 9	<b>1267</b>	38,5	0,6	0,7		-2,0
27	C	103	1970	5 / 5	<b>1314</b>	44,7	0,0	0,0-0,3		-2,0
28	F	specpr.	1999	4 / 4	<b>1401</b>	40,0	0,4	0,0		-3,5
29	D	103	1988	5 / 5	<b>1536</b>	43,1	0,8	0,8		-2,0
30	E	specpr.	1999	/ 4	<b>1550</b>	38,9			0,6	-5,0

## RESULTS

Table 1 shows results of measures within energy audit inspections in 30 apartments, in 13 not renovated MABs and short information about those apartments and MABs. The data arranged in progressive order by measured results of CO<sub>2</sub>

concentration level, view column 6 in Table 1. This order simplifies identification of represented data in Graph 1 and information about a particular apartment.

Explanation of data in Table 1 by columns:

1. inspected apartment's order by number from 1 till 30;

2. marking in alphabetic order from A till M within energy audit of the inspected 13 not renovated MABs, to make comparative analysis of measured data in apartments in the same MABs possible;

3. information about number of standard construction type of MAB or reference to special project solution „specpr.”;

4. the year when MAB was put into service;

5. number of apartments on each floor / total number of floors in the MAB;

6. measured indoor air CO<sub>2</sub> concentration level in apartment, ppm;

7. measured indoor air relative humidity level, %;

8. exhaust air velocity, measured by ventilation grid of natural ventilation exhaust channel in the kitchen, m/s;

9. exhaust air velocity, measured by ventilation grid of natural ventilation exhaust channel in the bathroom, m/s;

10. exhaust air velocity, measured by ventilation grid of natural ventilation exhaust channel in the toilet, m/s;

11. outdoor air temperature during measurements in apartment.

Empty cells indicate missing data. The indoor air temperature is not included in Table 1. The indoor air temperature varies between +16 to +24 °C in different rooms of the apartment. The temperature on the surface on indoor side of the building envelope varies from +12,8 to +24 °C, measured by thermographical inspection of the apartment.

#### ANALYSIS

The minimal indoor air temperature in living rooms is +18 °C defined in accordance with building codes of Latvia [7]; in general the human thermal comfort requirements for temperature varies from +20 till +24 °C. The results of temperature measures show that the minimum of normative temperature is not provided in part of different rooms of the apartment. The difference in temperatures in the rooms may be explained by the use of typical one-pipe heating system without possibility of individual regulation in existing MABs. Raised indoor air temperature in apartments near heat supply point or reduced indoor air temperatures in apartments with greater distance from heat supply point are typical issues for this solution. We can explain reduced temperature on the surface on indoor side of external building constructions with damages of constructions, thermal bridges, low thermal resistance and insufficient heating. Reduced radiant temperature provides local discomfort for people and leads to progression of condensate and mould on the construction surfaces.

Ventilation requirements for living areas in accordance with regulations of Latvia establish minimum of 3 m<sup>3</sup>/m<sup>2</sup> per hour of fresh air in living areas and bedrooms [7] or a minimum of 15 m<sup>3</sup>/h per person [9]. As shown in Table 1 (columns 8, 9 and 10) collected air flow rate measurements show that in certain parts of rooms the natural ventilation does not work, there is no traction. As shown by inspection results, some ventilation ducts are blocked by people, in some places ventilation ducts due to low quality of construction are not connected to main roads or contaminated with debris. Natural ventilation

operating principles have been degraded due to the initiative of individual citizens: installed new tight windows ensure sealing, which significantly reduces infiltration air flow; household exhaust fans installed in kitchens and toilets do not guarantee continuous space ventilation, as well as there is a risk that contaminated exhaust air may bypass between apartments. Living area ventilation intensity has not been analyzed in detail, because measurement data are not complete. There is also no detailed information about the number of users of the apartments to analyze the adequacy of ventilation in compliance with operation conditions.

Latvia building codes do not define CO<sub>2</sub> concentration level of living room indoor air. In Table 1 the collected data shows that in 16 out of 30 apartments CO<sub>2</sub> concentration level is  $\geq$  1000 ppm. Increased CO<sub>2</sub> concentration level can cause discomfort, headache, fatigue and other unpleasant sensations, however, the major threat to human health is induced by CO<sub>2</sub> concentration level above 5000 ppm.

Latvia building codes do not require maintaining living room indoor air relative humidity. Good comfort requirements require to keep 40 to 60 % relative humidity, for human health and construction safety 30 to 70 % relative humidity is a desired limit. Only 2 out of 30 measurements (~ 7%) show low moisture level, see Table 1. In specific climatic conditions in Latvia, Riga, the average outdoor temperature in October is + 7,2 °C and daily average relative humidity is 83% [10], without taking into account the indoor humidity gains, by heating the air to a minimum +18 °C, reaching the supply air relative humidity limit of 40%. Decreasing outdoor temperature, heating period requires indoor air humidification in Latvia. Average heating period is 203 days in Riga, Latvia, with the average outdoor temperature 0,0 °C [10].

We analyzed CO<sub>2</sub> concentration level and relative humidity in living rooms. Those values are shown in Fig. 1. In rooms where the main source of pollution is a human being, relationship between the space relative humidity and CO<sub>2</sub> is due to human physiological processes. The measurement results of statistical analysis confirmed correlation between space CO<sub>2</sub> level (ppm) and relative humidity (%) increase (Pearson correlation  $r = 0,49$ ,  $p = 0,006$ ).

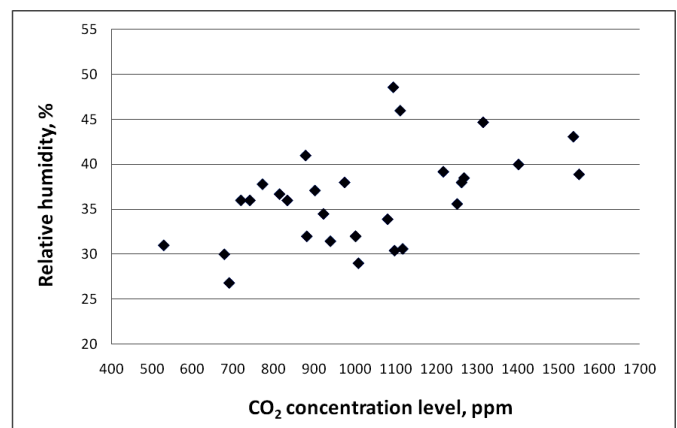


Fig. 1 Indoor air levels of CO<sub>2</sub> concentration (ppm) and relative humidity (%) results of measurements in 30 apartments in 13 MABs

Additional research is on this theme needed relevant to. In order to be able to argue that the data could be viewed as representative and can be used to estimate CO<sub>2</sub> concentrations based on indoor air relative humidity measurements, performed in similar open-air atmosphere in standard MAB with average indoor air temperature from +20 to +22 °C.

#### DISCUSSION

Taking into account regulatory requirements for ventilation in apartments in MABs and actually completed building energy audit inspection data, which suggests an increased omitted air infiltration through gaps [11], it can be predicted that the existing building indoor air CO<sub>2</sub> concentration level should be according to recommended standards - up to 1000 ppm [12, 13]. However, inspection and measurement data show that the increased air infiltration in local building construction defect places (along the window frames, panel seams), does not enhance effective natural ventilation of apartments. As a result of increased heat losses in buildings indoor climate does not provide healthy and comfortable conditions for humans as determined by the standards.

Some improvements in apartments, for example, household exhaust fan installation in apartments and adding to the natural exhaust ventilation ducts, as well as the replacement of double glazing windows in wooden frames ( $U \geq 2,5 \text{ W}/(\text{m}^2 \cdot \text{K})$ ) with double-glazed windows in PVC frames of uncontrolled quality, may cause inadequate ventilation in apartments and indoor climate deterioration both in the apartment and in the building as a whole.

The same IAQ issues are discovered in an ongoing IAQ monitoring project in MABs before and after renovation [14, 15]. The intermediate results show that IAQ is decreased in apartments with individual improvements and in MABs after partial renovation without modernization of ventilation system.

The main influence on the operational capability of the existing functional ventilation systems of MABs and, correspondingly, on the IAQ, is the behavior of the inhabitants.

#### CONCLUSIONS

Results of IAQ measurements approved ventilation problems and a reduced level of comfort.

Typical solution for MAB ventilation - with natural exhaust channels from the toilet facilities and kitchen premises, and not organized outdoor air infiltration through the leakages in the building envelope etc., not provide heat recovery from dissipated air and cannot guarantee the weather independent, suitable - for human comfort requirements - room for microclimate maintenance.

To improve the microclimate in the MABs, ventilation system must be updated in all apartments.

Actions that can increase energy efficiency of buildings, for example, heat insulation of building, carried out a complex with all of the engineering system restoration, improvement or modernization.

Planning adequate investment in buildings to improve energy efficiency and choosing modern, adequate and effective engineering solutions, it is possible to raise the comfort level of the living space and to reduce heat and thermal energy consumption. Arranging exhaust air heat recovery, it is possible to recover at least 50% of the heat required for supply air heating (without humidification) up to thermal comfort. Ventilation heat energy demand accounts for about 50 kWh/m<sup>2</sup> per heating season in the climatic conditions of Latvia.

The future studies will enclose IAQ monitoring in MABs through the heating season, to allow analyzing the correlation between IAQ parameters (especially CO<sub>2</sub> concentration level and relative humidity at different ventilation rates with humans as the main pollution source) in the climatic conditions of Latvia.

#### ACKNOWLEDGMENTS

Thanks to Dr.phys. L.Šnīdere and engineer Vilis Krūmiņš.

Research is implemented with financial support to I.Dimdiņa from JSC Latvijas gāze.

The described data were presented at the 8th International Conference "Indoor Climate of Buildings 2010" (High Tatras, Slovakia, November 29 – December 1, 2010) with the corresponding paper "Results of Living-Room Microclimate Parameter Measures in Multi-Apartment Buildings before Renovation" published in the conference proceedings.

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**Ēriks Krūmiņš**, M.sc.ing., received from Latvia University of Agriculture in 2007. Doctoral student of Latvia University of Agriculture, Department of Architecture and Building. Department Manager Deputy (house management since 2007), Manager of Repair Work Sector (2003-2007) – Rīgas domes Saimniecības pārvalde (Economic Government of Riga Council); Chairman and owner (1998-2003) – I.U. “SOLO RDB” (retail business); Co-owner (1993-1998) – SIA “INKRĒZE” (retail business).

Member of the Board of Society „Energofektivitātes ABC”. Member of LBS (Latvia Society of Civil Engineers).

E-mail: eriks.krumins@riga.lv

**Ize Dimdiņa**, M.sc.ing. from Riga Technical University in 2010. Doctoral student of Riga Technical University, Faculty of Civil Engineering, Institute of Heat, Gas and Water Technology.



Designer of HVAC systems - SIA “Indutek LV”, since 2007; Member of the board (2005-2007), department manager (2004-2005), project manager (2001-2004) - SIA “Pilsētmaju institūts Urban Art” (real estate management and development company); Member of the board (2004-2009) - SIA “Kompanjoni” (conference and recreation centre).

Member of: LSGŪTIS (Latvia Society of Heat, Gas and Water Technology Engineers); LEAA (Association of Energy Auditors of Latvia).

E-mail: ilze.dimdina@gmail.com



**Arturs Lešinskis**, Dr.sc.ing. received from Riga Technical University in 1992.

RTU Professor since 1998; Head of the board, SIA “Lafivents” (Ltd. company dealing with ventilation and air conditioning) since 1996; guest professor at Latvia University of Agriculture since 1976. Chairman of the board, LSGŪTIS (Latvia Society of Heat, Gas and Water Technology Engineers). Member of American Society of Heating, Refrigeration and Air-Conditioning Engineers.

E-mail: Arturs.Lesinskis@rtu.lv

#### **Ize Dimdiņa, Ēriks Krūmiņš, Arturs Lešinskis. Iekštelpu gaisa kvalitātes raksturlielumu mērījumu rezultāti nerenovētās daudzdzīvokļu ēkās.**

Esošo daudzdzīvokļu ēku ventilācijas sistēmu tipiskais risinājums – ar dabiskās nosūces kanāliem no dzīvokļu savietotajiem sanitārajiem mezgliem, virtuves telpām un neorganizētu ārējais pieplūdi caur ēkas neblīvumiem. Pētījuma mērķis – novērtēt nerenovētu daudzdzīvokļu ēku dabiskās ventilācijas sistēmas darbību ekspluatācijas apstākļos un iekštelpu gaisa kvalitātes atbilstību normatīvam, veselīgas vides un komforta prasībām.

Pētījumā apskatīti ēku energoauditā ietvaros veiktie iekštelpu gaisa kvalitātes mērījumi, konkrēti, CO<sub>2</sub> koncentrācijas līmeņa, temperatūras un relatīvā mitruma mērījumi, dabiskās ventilācijas nosūces gaisa plūsmas ātruma mērījumi.

Dzīvokļu īpašnieku individuāli veiktie uzlabojumi (piem., logu nomaiņa, sadzīves ventilatoru uzstādīšana), degradē ventilācijas sistēmas darbību. Apsekojumu un mērījumu dati apliecina, ka palielināta gaisa infiltrācija lokāli norobežojošo konstrukciju defektu vietās (gar logu rāmjiem, paneļu šuvēm), nenodrošina efektīvu dzīvokļu dabisku ventilāciju. Iekštelpu gaisa CO<sub>2</sub> koncentrācijas līmeņa mērījumu rezultāti 19 no 30 dzīvokļiem (13 tipveida ēkās) uzrāda rezultātu  $\geq 1000$  ppm, kas apstiprina nepietiekamu telpu ventilāciju. Rezultātā ir paaugstināti ēku siltumenerģijas zudumi un nav nodrošināta normatīviem atbilstoša, veselīga iekštelpu gaisa kvalitāte.

Lai uzlabotu iekštelpu gaisa kvalitāti un energoefektivitāti esošās daudzdzīvokļu ēkās, nepieciešams veikt ēku kompleksu renovāciju, kas ietver ventilācijas sistēmas atjaunošanu un modernizāciju. Siltuma atgūves potenciāls no izvadāmā gaisa sastāda ap 50% no āra gaisa uzsildīšanai (bez mitrināšanas) nepieciešamā siltuma daudzuma jeb aptuveni 50 kWh/m<sup>2</sup> apkures sezonā, Latvijas klimata apstākļos.

Turpmākie pētījumi paredz analizēt iekštelpu gaisa kvalitātes raksturlielumu saikāšības, īpaši CO<sub>2</sub> koncentrācijas līmeņa un relatīvā mitruma izmaiņas telpās ar atšķirīgu gaisa apmaiņu un cilvēku kā galveno piesārņojuma avotu, Latvijai raksturīgos klimata apstākļos.

#### **Илзе Димдина, Эрикс Круминьш, Артур Лешинскис. Результаты измерений параметров качества воздуха в нереновированных многоквартирных домах.**

Типовое решение системы вентиляции существующих многоквартирных домов - естественные экстракт-каналы из санитарных узлов и кухни квартиры и неконтролируемый приток наружного воздуха через неплотные стыки здания. Цель исследования - оценить способность системы естественной вентиляции нереновированных многоквартирных домов в условиях эксплуатации и качество воздуха в помещениях в соответствии с правилами комфорта и здоровой окружающей среды.

В настоящем исследовании проведен анализ данных, полученных во время энергетического аудита, в частности, измерения качества воздуха – уровня концентрации CO<sub>2</sub>, температуры и относительной влажности, скорости воздушного потока в экстракт-каналах естественной вентиляции.

Индивидуальные улучшения, сделанные собственниками квартир (например, замена окон, установка вентилятора), нарушают систему вентиляции. Данные обследований и измерений показывают, что увеличение инфильтрации воздуха локально в дефектных местах конструкций (вдоль оконных рам, стыков панелей), не обеспечивают эффективную естественную вентиляцию помещений. Измерения уровня концентрации CO<sub>2</sub> в воздухе помещений в 19 из 30 квартир (в 13 стандартных зданиях) представляют результаты  $\geq 1000$  ppm (частей на миллион), подтверждающие недостаточность вентиляции помещений. Это приводит к увеличению потерь тепла в зданиях и не гарантируется соблюдение законодательных требований здоровой среды и качества воздуха в помещениях.

В целях улучшения качества воздуха в помещениях и энергоэффективности существующих много квартирных домов, необходимо реализовать комплексную реконструкцию, которая включает обновление и модернизацию системы вентиляции. Потенциал утилизации тепла от удаляемого воздуха около 50% от необходимого количество тепла нагрева наружного воздуха (без увлажнения), или около 50 кВт·ч/м<sup>2</sup> в отопительном сезоне, в латвийских климатических условиях.

Дальнейшие исследования планируются в соответствии с результатами анализа качества воздуха в помещениях и характеристик соотношений, в частности, изменения уровня концентрации CO<sub>2</sub> и относительной влажности воздуха в помещениях с различными типами обмена воздуха как основного источника загрязнения, в климатических условиях Латвии.