INDOOR AIR QUALITY AND ENERGY EFFICIENCY IN MULTI-APARTMENT BUILDINGS BEFORE AND AFTER RENOVATION: A CASE STUDY OF TWO BUILDINGS IN RIGA

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ABSTRACT

We present an ongoing project which aims at monitoring IAQ in multi-apartment buildings (MABs) before and after renovation. We collected measures of indoor air microclimate parameters in 6 apartments of 3 MABs of standard construction buildings (type 464) in Riga, during the heating season of 2010/2011. In 3 apartments of one renovated building and in 3 apartments of two unrenovated buildings (on the first, middle and top floor), sensors of air temperature, relative humidity, CO_2 concentration level, and air flow velocity are located to find the average value of IAQ parameters, and to make calculations of indoor air exchange in each apartment. At the same time, the outdoor air temperature and relative humidity are measured. The measurements are made every minute, and the paper presents the data for duration of several months.

In general, the results show that the ventilation system must be updated in all apartments. The thermal energy for heating is reduced by about 50% in renovated MAB. The heat energy consumption in different apartments of the renovated building and temperature measures in all the project apartments demonstrate the necessity to change the heat consumption according to individual financial possibilities and comfort demands.

Key words: CO_2 concentration level, energy efficiency, heat energy consumption, indoor air quality, multi-apartment buildings

INTRODUCTION

Previous experience shows that renovation of ventilation systems is not a typical component of renovation of MABs in Latvia. As a consequence, rooms are not ventilated enough and the indoor air quality (IAQ) is reduced. This, in turn, leads to progression of the so called sick building syndrome (SBS). IAQ measures in 13 unrenovated MABs shows that the CO_2 concentration level in 19 of the examined 30 apartments was ≥1000, indicating insufficient ventilation (Dimdina et al., 2010).

The study was carried out in the frameworks of the Baltic Sea Transnational Cooperation Programme 2007-2013, within the project "Energy Efficient and Integrated Urban Planning (UrbEnergy)", which involved development of an internet portal for on-line monitoring of the indoor climate and consumption parameters of renovated and not renovated buildings in Latvia.

The project objective was to identify the microclimate problems in residential buildings before and after renovation, develop recommendations for residential indoor climate and energy efficiency, to test the practical effect of upgrades aimed at indoor air quality improvement, to draw public attention to residential indoor climate problems, to promote civic education and the progress of high-quality renovation of residential buildings.

MATERIALS AND METHODS

Project buildings and apartments

For the project, 5 (five) MABs in Riga were selected, in two types of standard residential buildings: three of the buildings were of the so called project type 464 (5 floors, 3 staircases, 45 apartments in each building), and two were of the so called project type 602 (9 floors, 2 staircases, 72 apartments in each building). Because the ownership of MAB apartments in Latvia is typically individual (each apartment has a separate owner), the measurements in all the selected apartments had to be agreed with the apartment owners. Because such agreement was not reached in some cases, the planned microclimate monitoring was not implemented in three apartments in one of the non-renovated 464-series building, but identical apartments were used in two nearby buildings. In addition, the total number of the planned measurements (98 measurement points in 12 apartments) was not achieved because of various technical problems (for example, sealed exhaust ducts) and human factors. As a result, not all monitoring data were fully secured from all measurement points, and in some cases the missing data have been imputed by using indicators from the corresponding measurement point in another, equivalent building within the project. In such cases, the methodology of calculations is explained in the notes to the corresponding results table (see Table 1).

IAQ parameters are measured in 3 apartments (on the first, middle and top floor) of two non-renovated MABs of the type 464 (464-N1 and 464-N2), and in 3 apartments (on the first, middle and top floor) of one renovated MAB of the type 464 (464-R), and in 2 apartments (on the top floor) of one renovated (602-R) and one non-renovated (602-N) MAB of the type 602. In this paper just the MABs of the type 464 are reviewed.

Standard 464.series MAB description (Pasaules bankas tehniskā vienība, 2002): construction year starting from 1961, five (5) floors, sectional type (with a staircase in the middle of each section), with basements and technical space on the attic level, with loggias or balconies; outer wall: 300 mm thick lightweight concrete panels, on outer corners of the balcony and stair area up to 420 mm thick lightweight concrete panels; windows and balcony doors: double glazing in wooden frames.

Renovation upgrades of the 464-series building in year 2008 (Jermaka, 2010): attic insulation with ecowool (200 mm); facade insulation with rock wool (100 mm); basement insulation with extruded foam (100 mm), common areas window and door replacement to double-glazed windows in PVC frames, installation of thermostats and heat meters (allocators) on each radiator.

The two unrenovated MABs 464-N1 and 464-N2 had the North oriented end-walls insulated, correspondingly in 2007 and 2005.

The schematic layout and photo (S end-wall, W facade with loggias) of the renovated 464-series building (464-R) and the two non-renovated buildings (464-N1 and 464-N2) are depicted in Figure 1.

The apartments for the IAQ parameter measurements were chosen, taking into account their location within the building. Individual upgrades in the apartments are:

- 464-R/middle (3) floor - extractor fan in the kitchen and in the combined sanitary facility;
- 464-R/top (5) floor - extractor hood in the kitchen, glassed loggia, combined sanitary facility;

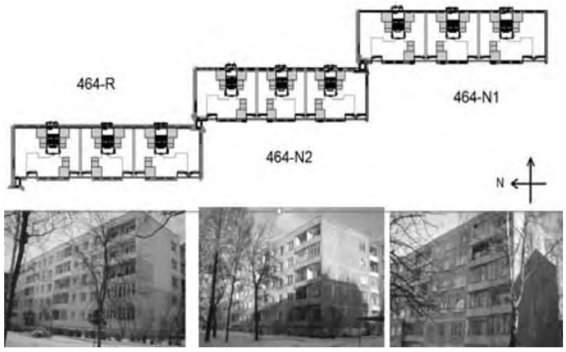

Figure 1. 464.series MABs photo and schematic location (renovated: 464-R; not renovated: 464-N1 and 464-N2).

- 464-N2/first (1) floor - recirculating hood in the kitchen;
- 464-N2/middle (4) floor - double-glazed windows in PVC frames, glassed loggia;
- 464-N1/top (5) floor - S end-wall insulated from inside (2004), new radiators (2009), extractor fan in the kitchen and in the combined sanitary facility.

Measuring equipment and measurements

For the indoor air parameter measurements, a complex measuring equipment was used, which was set up, in coordination with the apartment owner, in the owner's bedroom (about 1 m above the floor - the working area) or in the kitchen area (about 1 to 1,8 m above the floor). The equipment measurement accuracy (at 25^0C) is the following: for temperature ± $0,5^0$C, for relative humidity ± 3% of reading value; for CO_2 concentration to ± 40 ppm + 3% of reading value.

For the indoor corner temperature measurements a sensor with an accuracy of ± 0,3 K (at 25^0C) was used. For the measurements of exhaust ventilation ducts of the kitchen and lavatory, the measuring equipment with an accuracy of: air flow rate <0,5 m/s ± 7% of reading value (at 25^0C); temperature < $0,5^0$C (at 25^0C, > 0,5 m/s) was used.

The outdoor air temperature and relative humidity were measured approximately 1 m above the ground with an accuracy (at 25^0C) of ± 0,3 K, relative humidity ± 3% of reading value (at 30 ... 70% r.m.), ± 5% of reading value (at 10 ... 30% r.m. and 70 ... 90% r.m.), ± 10% of reading value (at 5 ... 10% r.m. and 90 ... 95% r.m.).

The planned reading period was 1 minute. If a reading was not made due to the technical reasons, the point value in the chart did not appear for the respective period. If the reading is performed, but the measuring equipment "has not provided an answer", the value is recorded outside of the measuring range, allowing it to be ignored during the data processing (details of data collection - see below).

At the present time, the total number of simultaneously measured parameters in MABs of the type 464 is 45. In each of 6 project apartments the air temperature, relative humidity and CO_2 concentration level in the bedroom or kitchen (Table 1) are measured; air temperature and air flow velocity in two exhaust ventilation ducts (from the kitchen and lavatory) are measured; in 1 project apartment the air temperature at the exterior corner is measured; outdoor air temperature and relative humidity are measured.

Data extraction, processing

The equipment that participated in the course of the data collection (Dimdiņa et al., 2010):
- controller - provides instantaneous measurements of temperature, relative humidity, carbon dioxide concentration and air flow rate of the object and object points;
- server (hardware and software) for data acquisition and processing - set up as a real physical IBM PC-type device which operates based on the Linux type environment, the server regularly communicates with the existing controllers, surveying the current (instantaneous) data values (data collected at 1 min intervals);

There are regular communication sessions taking place between the server and the controllers, during which the data are obtained from the controllers and transferred to the data processing module. Physical or transport-level disturbances are recorded in files.
Program modules ensure the data analysis by performing the following functions:
- separate the controller data from possible interference, which does not include physical or transport-level disturbance categories;
- make the data format adjustment and rounding of the data values: temperature - accuracy of $0{,}1^0C$, relative humidity - accuracy of 1%, CO_2 concentration - 0,001%, air flow rate – 0,1 m/s.

Thermal energy consumption calculation

The input of the district heating system of each MAB is equipped with an individual building heating substation enabled to count the total heat consumption for heating and hot water heating. The methodologies used to calculate the data on the building heat consumption and distribution of heating and hot water among the apartments depended on the building maintenance manager. In one building (464-series renovated building 464-R) the apartment owners had created their own association, and all the other buildings (464-N1, 464-N2, 602-R, 602-N) were managed by a municipality-owned maintenance company. In the building managed by the apartment owners association, the methodology was approved by the apartment owners meeting in accordance with the procedure prescribed by law. The methodology used by the municipality maintenance company has been determined by the Riga City Council (Riga City Council, 2010). Calculations are carried out once a month. The accounting policies and calculations described below are based on the information received from the particular building manager.
The methodology for calculating of thermal heating in the renovated 464-series MAB (464-R) (1):

$$Q_H=Q-Q_{hw}=Q-(V_{hw} * T_{hw} / T) \quad (1)$$

where Q_H – heat consumption for heating the buildings [MWh];
Q – total thermal energy consumption for heating and hot water delivered to the building [MWh];
Q_{hw} – heat consumption for hot water heating in the building [MWh];
V_{hw} – total hot water consumption in the building (the sum of the individual monthly hot water meter reading amount; the study calculations assumed a constant average of 145 m^3 of hot water consumption per building per month) [m^3];
T_{hw} – hot water heating rate (the operator's calculations assumed a constant amount of 2,75 LVL/m^3 in the 2010/2011 heating season, according to the actual average costs in the summer of 2010) [LVL/m^3];
T – heating rate (variable depending on the primary fuel (in the particular case - natural gas) prices and tax changes, heat supply in Riga in all project buildings is provided by the JSC "Rīgas Siltums") [LVL/MWh].

The buildings total heat consumption Q_H is calculated and distributed between the apartments according to the following scheme: 60% based on the heating square meters S_H and 40% based on individual heating (allocator) readings. All the allocator reading data processing and calculations are performed by a service company in accordance with the approved methodology, and taking into account the housing situation and other factors.
In the non-renovated 464-series (464-N1, 464-N2) MABs thermal heating calculations are performed on the basis of the Riga municipality building regulations (Riga City Council, 2010), under which (2):

$$Q'_H=Q-Q'_{hw}-Q_c=Q-(V_{hw}* T'_{hw} / T)-q_c* n \quad (2)$$

where Q'_H – heat consumption for heating buildings [MWh];
Q'_{hw} – heat consumption for hot water heating in the building [MWh];
Q_c – heat consumption for hot water circulation within the building [MWh];
T'_{hw} – hot water heating rate [LVL/m^3];
q_c = 0,1 MWh/apartments – heat consumption for ensuring the hot water circulation per apartment [MWh];
n – number of apartments in MAB.

In the non-renovated buildings, where individual heat metering in apartments is not provided, the buildings total heat consumption Q'_H is calculated and distributed among the apartments on the basis of heating square meters S_H.
This study uses the data about building and apartment thermal energy consumption for heating and hot water in accordance with the information provided by the maintenance manager and heat supplier.

Calculation of air exchange

In accordance with the laws (LR Ministru cabinets, 2009), the normative exchange of air L_{norm} in an apartment is calculated as:
- minimally secured air vent from the apartment, the sum of all the facilities required airflows: at least 50 m^3/h from a combined sanitary facility, at least 25 m^3/h from toilet facilities, at least 25 m^3/h from a bathroom, at least 60 to 90 m^3/h from a kitchen (from a kitchen with an electric oven or with a 2-ring gas stove - minimum of 60 m^3/h, from a kitchen with 3-ring gas stove - minimum of 75 m^3/h, from a kitchen with 4-ring gas cooker - at least 90 m^3/h);
- minimum air supply to be provided in the apartment, the sum of all the facilities required airflows: at least 3 m^3/m^2 per hour flow to the living areas and bedrooms.

In this study the IAQ measurements and calculations have been made in apartments with more than one living room or bedroom, so the exhaust airflow is assumed to be at least 90 m^3/h from the cooking area; the actual data about the type of the cooking stove were not collected. The bedroom and living room areas have been assumed to be average, according to the standard project plans; in all building types the apartment ceiling height is assumed to be 2,5 m, whereas the actual measurement or comparison with the data from the inventory file has not been done. In the calculations, the largest amount obtained by comparing the required exhaust and supply air quantity for an apartment is assumed to be the air exchange in the apartment. The air exchange L_{mes}, in accordance with the measurements of the airflow speed in the exhaust ventilation channels from the kitchen and toilet facilities, has been calculated in the following way (3):

$$L_s = s * 0,9 * v * 3600 \quad (3)$$

where L_s – airflow through the exhaust ventilation channel [m^3/h];
s – area of the exhaust ventilation channel, in all calculations assumed equal to 0,10* 0,15=0,015 m^2;
0,9 – applied correction coefficient for the distribution of the airflow speed within the cross-section of the ventilation channel;
v – measurement of the airflow speed [m/s]; 3600 – coefficient for transition from seconds to hours.

RESULTS AND DISCUSSION

Separately the results of IAQ measures are presented in Figures 2-6. On abscissa there is the period of the measures – date or time.
To reach the normative level of the air exchange L_{norm} in the apartments with the defined exhaust ventilation channel parameters (see *Calculation of air exchange*) and to provide the airflow exchange of L_{norm} =140 m^3/h in the apartments (with 2 exhaust ventilation channels) of the type 464 MAB, the necessary airflow speed is 1,44 m/s. Typical results of the measures show that the air velocity in exhaust ventilation channels does not exceed 1 m/s, and the ventilation problems increase in the upper floors and in renovated MAB without organized supply ventilation – see Fig.2.
The relative humidity level increases in the upper floors and in renovated MAB without organized supply ventilation – see Fig.3. Under specific outdoor climate conditions, excessively dry indoor air there is a problem with good ventilation without humidifying.
The CO_2 concentration level in the apartments is mostly dependent on the habits of the inhabitants. The CO_2 concentration level increases in the upper floors and in renovated MAB without organized supply ventilation - see Fig.4. Problems are most often created by blocked exhaust ventilation channels.

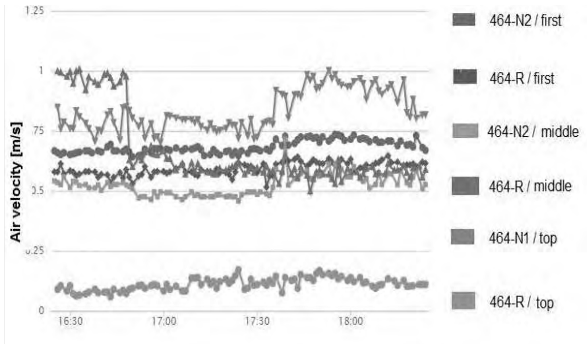

Figure 2. Air velocity in exhaust ventilation channel in kitchen (outdoor temperature about -10^{0}C).

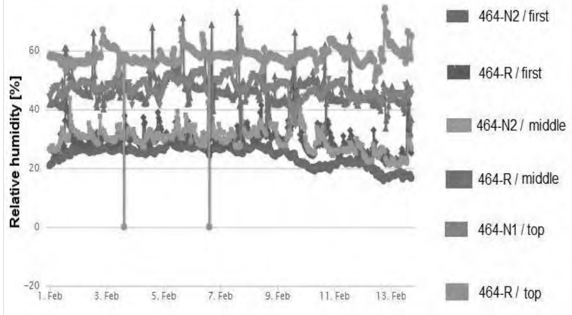

Figure 3. Relative humidity in apartments.

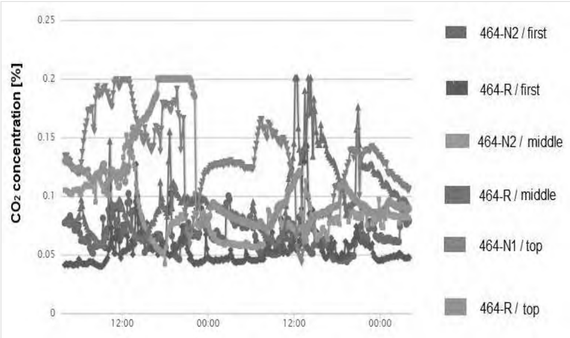

Figure 4. CO_2 concentration level in apartments (outdoor temperature -5…-10 ^{0}C).

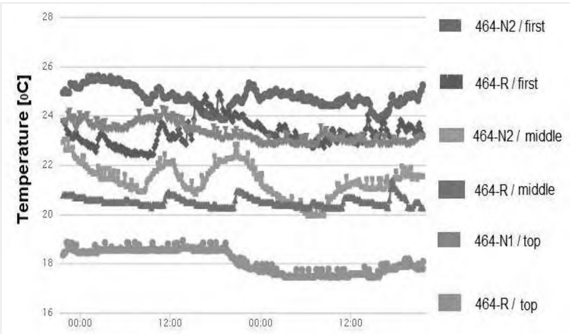

Figure 5. Temperature in apartments.

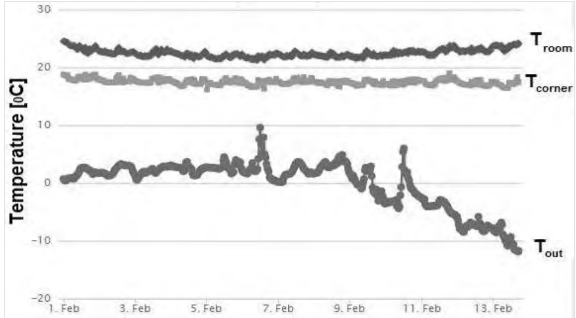

Figure 6. Temperature difference (464-N2/first floor)

The temperature measures in different apartments demonstrate the necessity to change the heat consumption in accordance with individual financial capabilities and comfort demands – see Fig.5.The temperature difference between the corner and the middle of a room in a typical unrenovated MAB exceed 5^{0}C – see Fig.6.

The average outdoor temperatures in Riga in 2010: October +6,05^{0}C (average by legislation +7,2^{0}C); November +3,32^{0}C (+2,1^{0}C); December -5,70^{0}C (-2,3^{0}C) – data of the Latvian Environment, Geology and Meteorology Centre.Table 1 presents location of the complex measurement equipment in the apartments and thermal energy consumption of MABs and individual heat consumption of apartments.

Table 1

Thermal energy consumption of MABs and apartments and location of complex measuring equipment

MAB/apartment floor	S_H, m^2	Location of compl.meas.eq.	Parameter, Dimension	X, 2010	XI, 2010	XII, 2010	Total
464-R	2342,91		Q, MWh	17,28	23,06	36,39	76,73
			$Q*1000/S_H$, kWh/m^2	7	10	16	33
464-R/first	65,01	kitchen, E facade		11	19	23	53
464-R/middle	38,44	kitchen, W facade		3	5	11	19
464-R/top	67,90	bedroom, N end-wall and W fasade with glassed loggia	$Q_{H*}1000/S_H$, kWh/m^2	2	5	11	18
464-N2	2342,91*		Q, MWh	30,3	46,51	73,13	149,94
			$Q*1000/S_H$, kWh/m^2	13	20	31	64
464-N2/first	65,65	bedroom, S end-wall and W fasade with loggia	$Q'_{H*}1000/S_H$, kWh/m^2	6	13	24	43
464-N2/middle	48,13	bedroom, W fasade with glassed loggia		6	13	24	43
464-N1	2342,91*		Q, MWh	37,1	51,66	80,22	168,98
			$Q*1000/S_H$, kWh/m^2	16	22	34	72
464-N1/top	64,59	bedroom, S end-wall and W fasade with loggia	$Q'_{H*}1000/S_H$, kWh/m^2	9	15	27	51

* comparison of the data from the inventory file is not done

CONCLUSIONS

The results of the indoor air quality measurements confirmed ventilation problems and indicated a reduced level of comfort. To improve the microclimate in MAB, the ventilation system must be updated in all apartments (Dimdiņa et al., 2010).
The air permeability difference between a typical blocked duct (with a plastic bottle) is 100% before the dismantling of barriers and 400% after the dismantling of barriers (Caune et al., 2010).
In the upper floors, the observed accumulated moisture in the building constructions is 20…35% higher compared to the lower floors, as well as condensate can be observed in the exterior wall corners. These are consequences resulting from the air exchange level that is 2 to 4 times below the normative.
The average bedroom temperature in the renovated buildings is 22…24 °C, at the outdoor temperature range between -5 °C and +5° C. The average temperature in the non-renovated buildings is 22…24 °C, with 15 °C observed in the corners. But lowering of the temperature is precluded by the risk of creating condensate in the corners. It is not possible to reach the temperature of 25 °C in the bathroom at apartment dwellers' preferred time; the actual temperature is 21…22 ° C (Caune et al., 2010).
The temperature measures in different apartments demonstrate the necessity to change the heat consumption according to individual financial capabilities and comfort demands. The thermal energy for heating is reduced by about 50% in the renovated MAB.
Activities that can increase the energy efficiency of buildings, for example, heat insulation of buildings, must be carried out in a complex with all of the engineering system restoration, improvement, or modernization.

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