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The Performance of the Ventilation in Estonian Retrofitted Apartment Buildings

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Abstract

The paper discusses the issues of energy efficiency and indoor climate after retrofitting ventilation systems in apartment buildings. The performance of ventilation was studied in field measurements of different type of Estonian apartment buildings. Indoor air CO₂ levels and airflow were measured in 20 renovated apartment buildings. Airflow and CO₂ levels were analyzed in the case of natural ventilation, room based air handling units, mechanical exhaust system and mechanical supply-exhaust ventilation. In the case of mechanical exhaust ventilation system, the building was equipped with an exhaust air heat pump for exhaust air heat recovery. The underlying factors of problems like the quality of maintenance, the reduction of the exhaust air flows in the case of low supply air temperatures, mistakes in designing and low building quality, have also been analyzed.

Keywords - indoor air quality; CO₂ concentration; air change rates; exhaust air heat pump; natural ventilation; room-based ventilation units

1. Introduction

The performance of residential ventilation systems plays an important role in good indoor air quality. At the same time, the energy consumption of the ventilation systems in apartment buildings is a considerable part of the total energy consumption of buildings. In the review of ventilation in European dwellings, it is pointed out that the ventilation of residential spaces in Nordic countries is often poor [1]. Renovation of ventilation systems is important because as a result of refurbishing, the airtightness of the building envelope increases and as many buildings have natural ventilation, the air exchange rate is reduced. That is the reason why a number of studies on the ventilation and indoor air quality in apartment buildings have been carried out at Tallinn University of Technology [2],[3],[4],[5].

The study discusses the issues of energy efficiency and indoor climate in retrofitted ventilation in apartment buildings. The paper is based on long-term parameter measurements of different type ventilation systems. To show the quality of the indoor

climate before the renovation process started the paper highlights the results of the previous research on Estonian old apartment buildings [6].

2. Methodology

In accordance with the requirements of regulation no. 38 of the Government of the Republic of Estonia [7], the living area must have natural or technical ventilation, which guarantees the air exchange necessary for human activity. According to the requirements in Estonia EVS-EN 15251:2007 [8] the air velocity in living spaces, the volume of the room per person and the content of harmful substances in the indoor air must not exceed the values permitted. In Estonia, the indoor air CO₂ concentration is considered to be the standard of the indoor environmental input parameters and designing criteria CR 1752 [9]. The parameters are described in Table 1.

Table 1: Class of the indoor climate for rooms with human activity by CR 1752 [9]

Category	Expected percentage dissatisfied, %	Indoor air CO ₂ concentration, ppm
II (B)	20	1010
III (C)	30	1540

According to the standard for determining the initial parameters of energy efficiency, it is possible to deduce the airflow according to the measurements of CO₂ concentrations in rooms where the main source of indoor pollution are people. This is called the metabolic CO₂ method. The air exchange in a room is possible to assess, as in

$$C = C_v + \frac{m}{L} - (C_v + \frac{m}{L} - C_0) \cdot (e^{-\frac{L}{V}\tau}) \quad (1)$$

In (1) C is the indoor air concentration of CO₂ at time (g/m^3), C_v the concentration of CO₂ in the external air (g/m^3), C_0 the concentration of CO₂ in the indoor air at time 0 (g/m^3), L the volume flow rate of air entering the space (m^3/h), m the volumetric indoor emission rate of CO₂ (g/h), V the volume of indoor space (m^3) and τ is the interval since $t = 0$.

The rate of ventilation affects indoor environmental conditions including air pollutant concentrations that, in turn, may modify the occupants' health or perceptions [10]. The performance of ventilation was assessed based on the target values from the standard EVS-EN 15251:2007. The II indoor climate category (normal level of expectation, for new buildings and major renovations) and the III indoor climate category (acceptable, moderate level of expectation, for old buildings) was selected for comparison. The general ventilation airflow in new apartments (indoor climate category II) should be at least $0.42 \text{ l}/(\text{s}\cdot\text{m}^2)$ or 0.6 h^{-1} and airflows in living rooms and bedrooms should be at least $1.0 \text{ l}/(\text{s}\cdot\text{m}^2)$ or $7 \text{ l}/(\text{s}\cdot\text{person})$. The general ventilation airflow in old apartments (indoor climate category III) should be at least $0.35 \text{ l}/(\text{s}\cdot\text{m}^2)$ or 0.5 h^{-1} and airflow in living rooms and bedrooms should be at least $0.6 \text{ l}/(\text{s}\cdot\text{m}^2)$ or $4 \text{ l}/(\text{s}\cdot\text{person})$.

According to the II indoor climate category, the exhaust airflow from the kitchen should be 20 l/s, from the bathroom 15 l/s and from WC 10 l/s. The same airflow according to the III category is 14 l/s from the kitchen, 10 l/s from the bathroom and 7 l/s from WC.

Ventilation airflow was measured with an anemometer (Testo 435). The indoor air CO₂ levels and airflow were measured in 20 renovated apartment buildings. In each building, 4 apartments were studied. Airflow and CO₂ level were analyzed in the case of natural ventilation, room based air handling units, mechanical exhaust system and mechanical supply-exhaust ventilation. In the case of mechanical exhaust ventilation system, the building was equipped with exhaust air heat pump for exhaust air heat recovery. In two buildings which were retrofitted using mechanical exhaust ventilation system, fresh air radiators were installed. Fresh air radiator system consists of outdoor air grille, panel radiator, air intake channel and air filter. Fig 1 describes the fresh air radiator which is installed in the apartment building and the infrared image shows how the outdoor air that enters into the radiator. The outdoor air is heated in the fresh air radiator but at the same time, there is a problem with the low surface temperature of the air intake channel.



Figure 1. Fresh air radiator (left) and the infrared image of the same radiator (outdoor air temperature -6 °C)

Room-based ventilation units were installed in 20 % of studied houses. All the apartments were equipped with regenerative ceramic heat exchanger and axial fan (Fig. 2). This type of single-fan-based units work in cycles, switching between supply and exhaust mode in every 60 - 70 seconds. During the exhaust cycle heat from the warm exhaust air is accumulated in the ceramic comb-like heat exchanger and is then used to heat up cold outdoor air during the supply cycle. Some of these devices are equipped with frost protection temperature sensor with launches the defrost cycle if necessary.

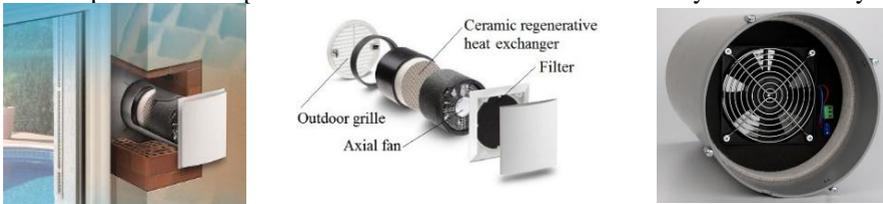


Figure 2. Room based AHU-s with regenerative ceramic heat exchanger

Mechanical supply-exhaust systems were installed in 5 % of the studied houses. The ventilation units were installed under the corridor ceiling and equipped with plate heat exchanger (with heat recovery figure 83 %) and electric heating coil. Inside the apartments, the air was exhausted from kitchen hoods, toilets and bathrooms. Supply air units were installed in living rooms and bedrooms. As we observed only 4 apartments with corridor based supply-exhaust ventilation units it is not possible to make thorough conclusions on these measurement results. That is the reason why this system is not analyzed as thorough as other solutions.

3. Results

A. Indoor air quality of existing Estonian apartment buildings

The cross-sectional study about the performance of ventilation was carried out in different types of apartment buildings during the period from 2007 to 2012 [6]. Studied old concrete large panel apartment buildings were built between 1955 and 1990, old brick apartment buildings between 1955 and 1990. From each building, 1 to 3 apartments was selected into indoor climate study. Typically an apartment was selected from one of the upper floors and the ground floor. Apartments consisted of one, two or three rooms, with a separate kitchen, entry, and sanitary rooms.

Indoor air CO₂ levels were measured in 83 apartments of old concrete and brick building. The measured data was analyzed and uncertain measurements were not taken into account. Two third of indoor air CO₂ measurements were taken place in heating period and one third in the summer period. The average indoor air CO₂ level of all the measurements was 1030 ppm, the minimal measured level was 278 ppm and maximum level was 4000 ppm (highest level of used measuring device). Minimal, maximal and average indoor air CO₂ concentrations in studied apartment buildings are described in Fig. 1.

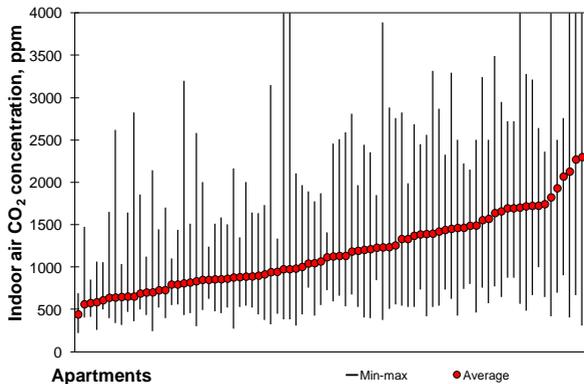


Figure 3. Minimal, maximal and average indoor air CO₂ concentrations in studied apartment buildings

According to the earlier studies of the indoor air quality in old Estonian apartment buildings [6], the air exchange rate is needed to increase. On this basis, the Government

has started large-scale campaign to retrofit the buildings in a way that improves their indoor climate and reduces the energy consumption. The studied buildings are part of this renovation campaign. The following analysis examines how the previously outlined ventilation systems have performed and what are the main issues of concern.

B. Indoor air CO₂ content of studied buildings

The indoor air CO₂ concentration in the studied apartment buildings varied from 320 to 3500 ppm. The CO₂ content in the indoor air corresponded to III class 81 % of the time in the case of natural ventilation, 86 % in the case of the room based heat recovery ventilation and 88 % in the case of the mechanical exhaust system with heat pump heat recovery (Fig. 4).

Bearing in mind the fact that in determining the initial parameters of energy efficiency, the standard permits the CO₂ content to exceed the maximum values of 5 % in the winter period, in 10 % of the investigated apartments, the CO₂ content in the indoor air corresponded to III class values.

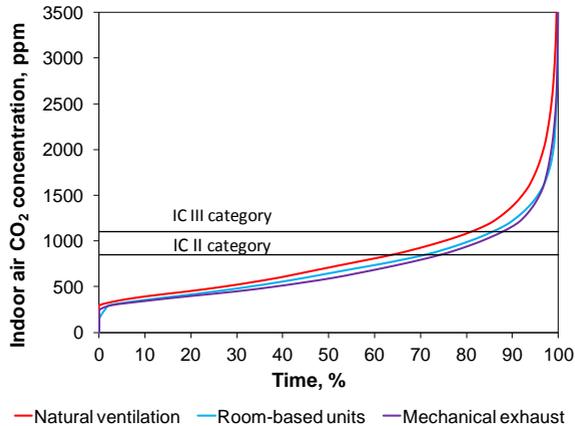


Figure 4. The cumulative distribution of CO₂ concentration in the case of the studied ventilation systems

C. Air exchange in apartments

To compare the different ventilation solutions, the airflow in apartments was measured. In the case of natural ventilation, the average exhaust airflow is 5.6 l/s, in the case of the room based ventilation units the average airflow is 7.0 l/s and in the case of mechanical ventilation the average airflow is 11.0 l/s. Fig. 5 shows the exhaust airflows in different ventilation systems and apartments.

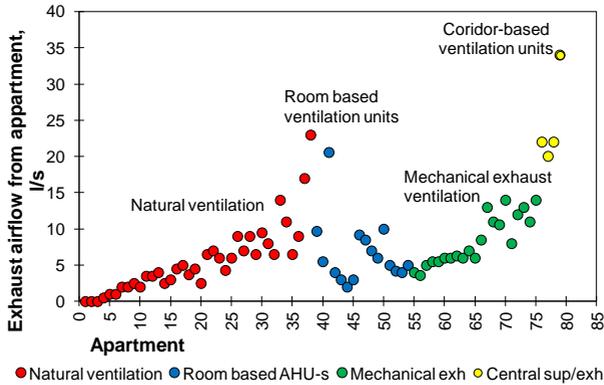


Figure 5. The exhaust airflow in the case of the studied ventilation systems

The situation was the worst in the case of renovated natural ventilation. The average air exchange rate was 0.08 h^{-1} and the average airflow per surface area of an apartment was $0.06 \text{ l/(s}\cdot\text{m}^2)$. The air exchange did not meet the requirements of the III indoor climate class in any of the studied apartments with renovated natural ventilation. The measured air exchange rates and the airflow per surface area are shown in Fig 6.

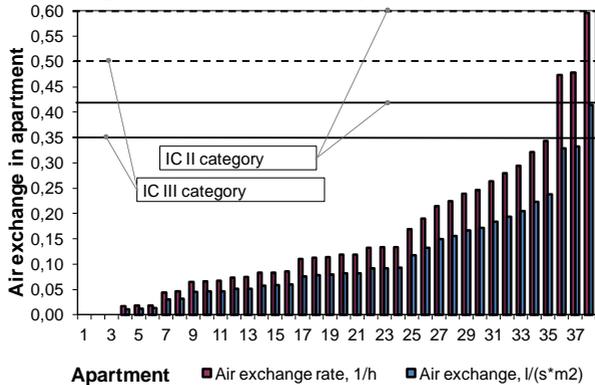


Figure 6. The measured air exchange rate in the case of natural ventilation

According to the measurements of the room based heat recovery ventilation units, the average air exchange rate was 0.18 h^{-1} and the average airflow per surface area of an apartment was $0.12 \text{ l/(s}\cdot\text{m}^2)$. The air exchange rate meets the requirements of III class in 6 % of the apartments. The measured air exchange rates and the airflow per surface area are shown in Fig 4.

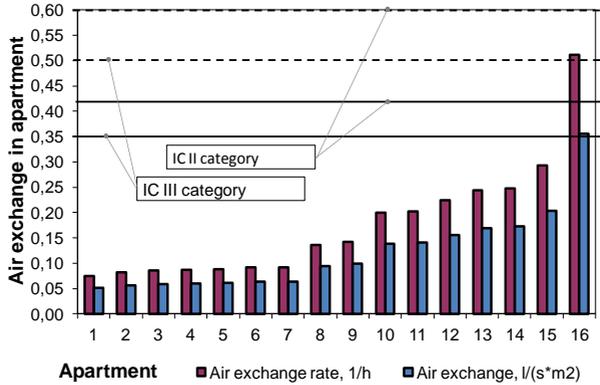


Figure 7. The measured air exchange rate in the case of room-based ventilation units

According to the measurements of mechanical exhaust ventilation, the average air exchange rate was 0.27 h^{-1} and the average airflow per surface area of an apartment was $0.19 \text{ l/(s}\cdot\text{m}^2)$. The air exchange rate meets the requirements of III class in 9 % of the apartments. The measured air exchange rates and the airflow per surface area are shown in Fig 5.

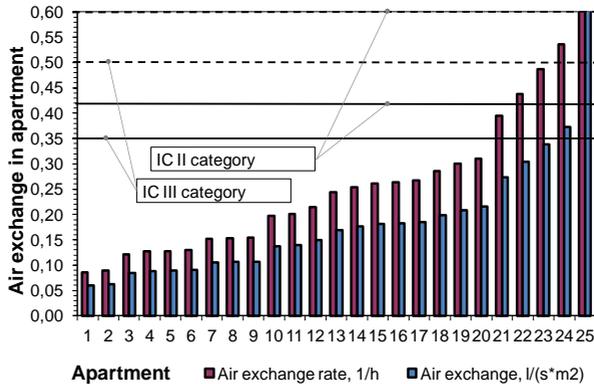


Figure 8. The measured air exchange rate in the case of mechanical exhaust ventilation

4. Discussion

The reduction of ventilation airflow in the studied buildings is mainly related to supply air temperature which is too low to ensure thermal comfort. In case the natural ventilation systems the air exchange rate was mainly reduced by closing the fresh air dampers. But there were also problems with the technical condition of the exhaust air devices and exhaust shafts. There were not transfer air grilles in kitchens, toilets and bathrooms which also reduced the designed airflows. The main conclusion of the

behavior of the residents is that the natural ventilation does not ensure sufficient air exchange rates and the thermal comfort in Estonian cold climate conditions.

In case the mechanical exhaust ventilation system the airflow was reduced by switching the fan to lower speed. The most common problem was related to the old exhaust air devices which were not replaced with modern exhaust valves or grilles. During the study, we detect that in some cases the exhaust air devices were not even connected to ventilation ducts. If the old natural ventilation shafts were used for the mechanical exhaust system then the technical condition of the exhaust shafts was not improved by the installation. The result of the described problem is the situation where the ventilation system is unbalanced. In the same way as the other studied systems the kitchens, toilets and bathrooms did not have transfer air grilles and the technical condition of the exhaust shafts was poor. We also detect important deficiencies of the maintenance service of ventilation systems. For example, the filters were not changed as often as necessary and the systems were not monitored to find the critical errors.

In some cases, the fresh air radiator systems were used but it did not significantly raise the supply air temperature. The fresh air radiators also added the problem with cold floors near the radiator. These problems were mainly caused by the misplacement of the intake air duct. We also made some additional temperature measurements to see how the fresh air radiators work in case of proper installation. Fig. 9 describes the cumulative distribution of room temperature, supply air temperature from fresh air radiator and the surface temperature of the intake chamber in winter conditions. The supply air temperature to the room was over 16 °C 83 % of the time. There were problems with low temperatures of air intake channel, the surface temperature of the intake channel was over 16 °C only 2.6 % of the time and the temperature was below the 10 °C 4 % of the measuring period. If fresh air radiators are correctly installed then it is possible to ensure the thermal comfort in the rooms easier and the residents do not need to close fresh air intake openings so often.

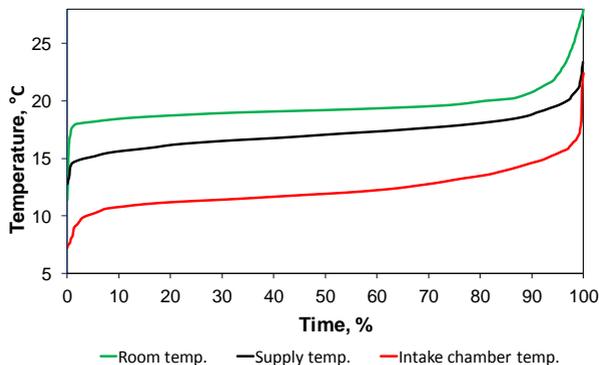


Figure 9. Cumulative distribution of the room temperature, supply air temperature from fresh air radiator and the surface temperature of the intake chamber (outdoor air temperature between -8 to +10 °C)

In case the room-based ventilation units, there was problem with the incorrect dimensioning of the fans. The units were designed to work at the highest possible airflow. Working at the highest speed level generates the high sound power levels and the people switched these units to the 30 % of the maximum airflow. Another problem was caused by the low temperature of supply air and that is why the airflow was reduced in the same way as previously described. To detect the cause of the problem the measurements of in- and outdoor pressure differences were made. These measurements showed that the problem was mainly caused by the large negative pressure in the first-floor apartments (Fig. 10). In the case of 5-storey buildings the underpressure in 1st-floor apartments was as high as -20 Pa. In 9-storey apartment buildings, the in- and outdoor pressure difference went up to 30 Pa. At the same time, the exhaust airflow of the installed room-based units decreased significantly. For example, if the unit worked at 30 % speed level and the underpressure in the room was -8 Pa then the supply airflow was 2 times higher than the exhaust airflow from the room. As the exhaust airflow was lower than supply airflow then the heat recovery figure of the unit dropped down to 30 % and the supply air temperature was too low to ensure thermal comfort.

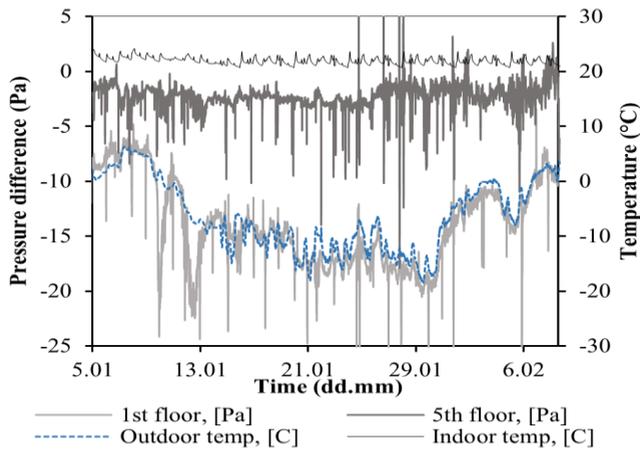


Figure 10. Measured in- and outdoor pressure differences in 1st and 5th floor apartments and indoor and outdoor air temperature in heating season

5. Conclusions

The performance of ventilation was studied in the field measurements of different types of Estonian apartment buildings. Indoor air CO₂ levels and airflow were measured in 20 renovated apartment buildings. The airflow and CO₂ level were analyzed in the case of natural ventilation, room based air handling units, the mechanical exhaust system and mechanical supply-exhaust ventilation. The CO₂ content in the indoor air corresponded to III class 81 % of the time in the case of natural ventilation, 86 % in the case of the room based heat recovery ventilation and 88 % in the case of the exhaust

heat pump heat recovery ventilation system. To compare the different ventilation solutions, the airflow in apartments was measured. In the case of natural ventilation, the average exhaust airflow is 5.6 l/s, in the case of the room based ventilation units the average airflow is 7.0 l/s and in the case of mechanical ventilation the average airflow is 11.0 l/s.

It is possible to conclude that the natural ventilation does not ensure sufficient air exchange rate and the thermal comfort. That is the reason why that solution is not the best possible way for retrofitting ventilation systems in Estonian apartment buildings. At the same time, studied mechanical ventilation systems considered also many incorrect solutions. The main problem why ventilation airflow was reduced in the studied buildings is related to low supply air temperature. The measurements showed that the supply air temperature was too low to ensure thermal comfort. In the case of room-based ventilation units, it is very important to design the fans in a way that the airflow is ensured in underpressure conditions. The other problems were related to the lack of maintenance service, old exhaust devices and unbalanced ventilation systems.

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