AIRTIGHTNESS AND VENTILATION OF NEW ESTONIAN APARTMENTS CONSTRUCTED 2001-2010

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ABSTRACT

The performance of ventilation and airtightness of the building envelope was studied in field measurements in recently constructed Estonian apartment buildings. The buildings were selected with different building envelopes and ventilation systems. The mean air leakage rate at the pressure difference of 50 Pa in the database was 1.7 $m^3/(h \cdot m^2)$. The mean air change rate at the pressure difference of 50 Pa from the database was 2.3 h^{-1}.
Ventilation airflows in apartments were low in general, resulting in bad indoor air quality. Only in a few apartments did the general airflow correspond to the requirements of indoor climate category II. Together with increasing air tightness of the building envelope, more attention should be paid to the performance of ventilation. The capacity of the ventilation system is not the only concern. Only increasing the ventilation airflow, without proper design (noise reduction, avoiding draft, energy performance, etc.), may not guarantee good results.

KEYWORDS
Airtightness of building envelope; Performance of ventilation;

INTRODUCTION

Energy performance of buildings and indoor air quality are becoming more important in many European countries – especially when the latest version of EPBD (European Energy Performance of Buildings Directive) calls for all new buildings to be nearly-zero energy by the end of 2020. This sets higher requirements on performance of ventilation and airtightness of the building envelope.

Air tightness of building envelopes directly affects indoor quality (health, thermal comfort), hygrothermal performance, noise and fire resistance, and energy consumption of the building. Jokisalo et al. showed that in Finnish cold climate infiltration causes about 15–30% of the energy use of space-heating, including ventilation, in a two-story detached house, when the building leakage rate is typically (n_{50} = 3.9ach), while the corresponding proportion is about 30–50% in a leaky house (10ach). Because the correlation between the airtightness of the building envelope and the infiltration rate is almost linear, heating energy use of the houses also increases almost linearly at the same time. Therefore, the preceding correlation reduces into a simple rule of thumb: a one unit change in n_{50} corresponds to a 7 % change in the energy use of space heating, including ventilation. At the same time, the change in total heat energy use is about 4%. In the studied cases, these increment percentages vary from 4 % to 12 % regarding space heating, or from 2 % to 7 % regarding total energy use. The variation of these percentages mainly results from different wind conditions [1].

Therefore airtightness has become a single requirement in low energy buildings. In certification of new passive houses, the Passive House Institute requires air leakage rates below 0.6 air changes per hour at 50 Pascals pressure difference.

A good principle regarding the balance between airtightness and ventilation is: « *build tight — ventilate right* ». To guarantee indoor air quality, the performance of ventilation in airtight buildings is an important issue. If buildings become more airtight, leakage airflow is smaller and ventilation airflow should be larger. This is partly the reason, why in many countries the ventilation airflows are increased. But just increasing the ventilation airflow may not guarantee good results. It is not only a question of what the capacity of ventilation system is, but also the way how inhabitant uses the ventilation, how the ventilation is designed and built (noise reduction, avoiding draft, energy performance, etc.). Because there are many unknowns in the final performance of ventilation and airtightness of the building envelope, field measurements can give a good overview of the situation.

To give an overview of the final performance of the ventilation and airtightness of the building envelope in Estonian modern apartment buildings, field measurements were carried out in 28 buildings built between 2000 and 2010. The study is a part of the research project about decreasing environmental impact of buildings by improving energy performance of buildings in Estonia, and collecting a database of airtightness in Estonian apartment buildings.

METHODS

Studied buildings

63 apartments from 28 buildings were investigated in a cross-sectional study of the technical condition of recently built apartment buildings. The airtightness of the building envelope was measured in 26 apartments in 23 buildings. Ventilation airflows were measured in 30 apartments.

Buildings were selected with different external wall structures (Figure 1, left) and with different ventilation systems (Figure 1, right). The selection should represent an average of recently built Estonian apartment buildings.

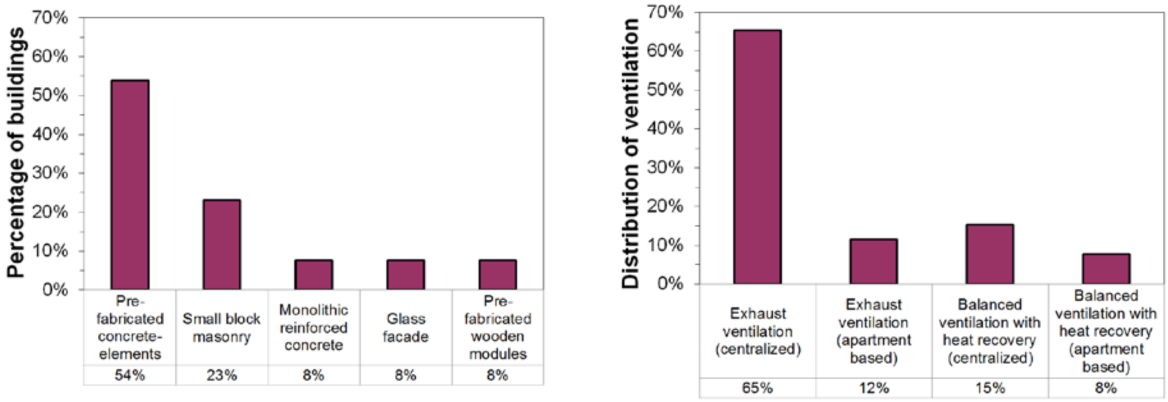

Figure 1. Distribution of studied apartments according to external wall type /left) and ventilation system (right).

Measurement methods

The air tightness of each apartment was measured with the standardized fan pressurization method [2], using "Minneapolis Blower Door Model 4" equipment (flow range at 50 Pa 25-7 800 m^3/h, accuracy ±3 %). To determine the air tightness of the building envelope, depressurizing and pressurizing tests were conducted with closed exterior openings, windows and doors and sealed ventilation ducts. To compare air leakage of different apartments, the air flow at pressure difference 50 Pa was divided by the apartment's internal envelope area (including intermediate walls) resulting air leakage rate at 50 Pa q_{50}, $m^3/(h \cdot m^2)$ or by the internal volume of the building, resulting in an air leakage rate at 50 Pa n_{50}, h^{-1}.

To determine typical air leakage locations and their distribution during the winter period, an infrared image camera FLIR Systems E320 was used (accuracy 2% or 2°C, measurement range: -20…+500°C). The temperature difference between the indoor and outdoor air was at least 20°C. Thermography investigations were conducted twice: first, to determine the normal conditions, the surface temperature measurements were performed without any additional pressure difference, and then to determine the main air leakage locations, the 50 Pa negative pressure under the envelope was set with fan pressurization equipment. After the infiltration airflow had cooled the inner surface (~30…45 min) of the envelope, the surface temperatures were measured with the infrared image camera from the inside of the building.

Ventilation airflows were measured with an anemometer (SwemaFlow 233 (accuracy ±4 % read value, minimum 1 l/s, measurement range 2 to 65 l/s)). The supply air flow rates were measured with a manometer Alnor/TSI AXD610 Digital Differential Micromanometer.

Assessment criteria

Requirements on airtightness of the building envelope is different country by country and in different standards [3][4]. In Estonia, the first requirement on the envelope's air tightness for apartment buildings was set in 1995: air leakage rate should be $q_{50} < 3.0$ $m^3/(h \cdot m^2)$ [5]. The minimum requirements on energy performance of buildings [6] suggest that the general air leakage rate could be $q_{50} < 1.0$ $m^3/(h \cdot m^2)$, and to avoid problems due to moisture convection critical joints should be made airtight.

Requirements on indoor climate are set in the standard [7]. The indoor air quality is expressed as the required level of ventilation. The general ventilation airflow in new apartments (indoor climate category II) should be at least 0.42 $l/(s \cdot m^2)$ or 0.6 h^{-1} and airflows in living rooms and bedrooms should be at least 1.0 $l/(s \cdot m^2)$ or 7 l/(s·person).

From measurement results, the reference value of air tightness for different types of buildings was calculated. The reference value $q_{50,delc}$ (Eqn. 1) represents median value (50% fractal) with a confidence level of 90% for air tightness. The reference value of air tightness is applicable for energy calculations, when air tightness is not measured or the air tightness base value given in energy performance regulation is not suitable to use (too large or too small).

$$q_{50,decl} = \overline{q_{50}} + k \cdot \sigma_{q50}, \ m^3/(h \cdot m^2) \quad (1)$$

where: $\overline{q_{50}}$ is the mean value of air tightness of this building type, $m^3/(h \cdot m^2)$; k is the factor which takes into account the median value with a confidence level of 90% (Eqn. 2), and σ_{q50} is standard deviation of air tightness measurement results for this building type.

$$k = \frac{1.645}{\sqrt{n}} \quad (2)$$

where: n is the number of measurements

RESULTS

Airtightness of building envelope

The mean air leakage rate at the pressure difference of 50 Pa in the database was 1.7 $m^3/(h \cdot m^2)$, the minimum being 0.8 $m^3/(h \cdot m^2)$ and the maximum 4.6 $m^3/(h \cdot m^2)$. The mean air change rate at the pressure difference of 50 Pa from all the data was 2.3 h^{-1} (minimum being 0.9 h^{-1} and the maximum 6.6 h^{-1}). The average values of air leakage rates and air change rates at 50Pa pressure difference of all measured apartments are shown in Figure 2.

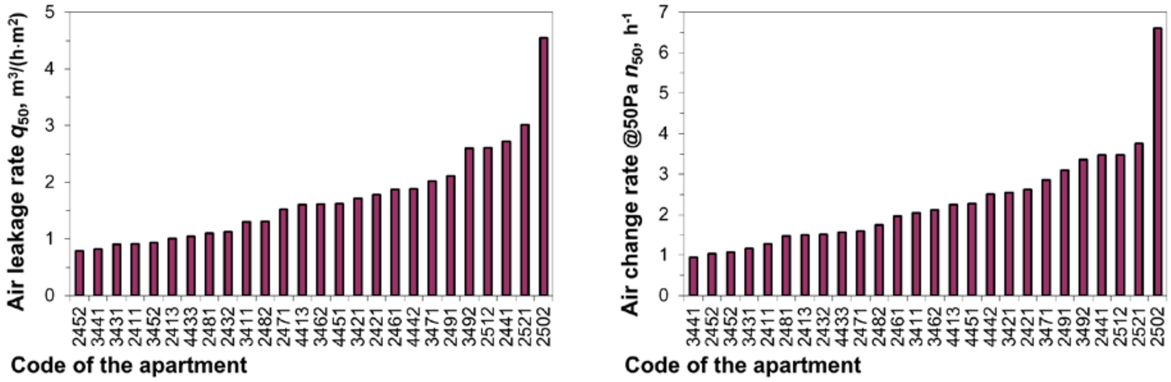

Figure 2. Air leakage rate q_{50} (left) and air change rate n_{50} (right) of all apartments.

Airtightness measurements show only a small difference between different building types (q_{50}=1.5…2.2 $m^3/(h \cdot m^2)$ and n_{50}=2.2…2.7 h^{-1}), Figure 3. It shows that it is possible to build airtight building envelopes within all types of structures. A larger deviation within the same building type shows that the quality of construction work can be a stronger influence.

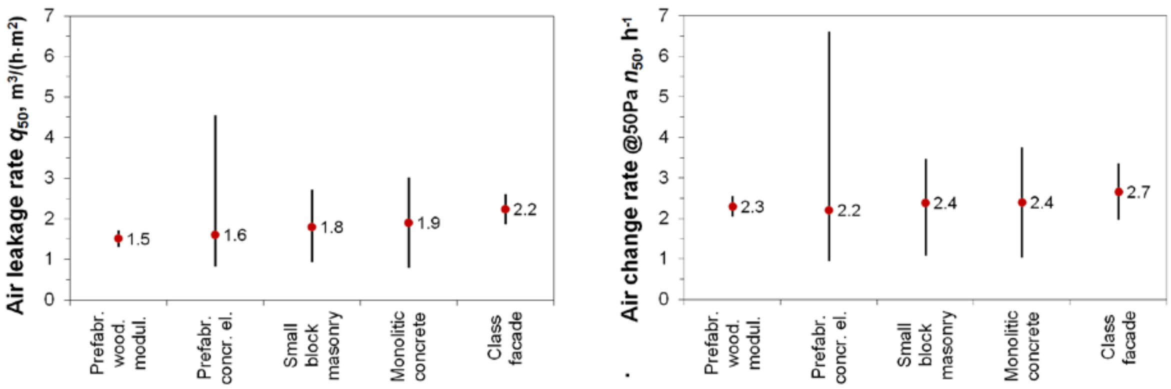

Figure 3. Air leakage rate q_{50}, $m^3/(h \cdot m^2)$ (left) and air change rate n_{50}, h^{-1} (right) of different building types.

By comparing current results with previous airtightness measurement results done in Estonia it shows that modern building envelopes are tighter, see Table 1. Older apartment buildings built with concrete and brick show similar airtightness, while old wooden apartment buildings are the leakiest.

Airtightness of the building envelope influences the heating energy consumption. Energy audits of buildings are commonly done with limited resources without airtightness measurements. Nevertheless, estimated values should be sufficiently on the safe side, to avoid too optimistic economic estimations. Reference values of airtightness that represent median values with a confidence level of 90% can then be used, see Table 1.

Type of the apartment building	Air leakage rate q_{50}, $m^3/(h \cdot m^2)$		Air change rate @50Pa n_{50}, h^{-1}	
	Average	Reference value	Average	Reference value
Modern buildings built 2000-2010 [current study] 26 apartments	1.7	2.0	2.3	2.7
Prefabricated concrete elements, 1960-1990 [8] 19 apartmnets	4.2	4.7	6.0	6.8
Brick walls, 1960-1990 [9] 30 apartments	4.0	4.4	5.7	6.4
Wooden structures, 1900-1940 [10] 35 apartments	10	11	13	14

Table 1. Comparison of airtightness of apartment buildings with different structures in Estonia.

Typical air leakage places in modern apartment buildings were:

- Leakages around the windows (Figure 4);
- Junction of the roof/floor with the external wall;
- Junction of the ceiling with the external wall;
- Junction of the separating walls with the external wall (Figure 5);
- Penetrations of pipes through the external wall;
- Surroundings of the fresh air valves in the external wall.

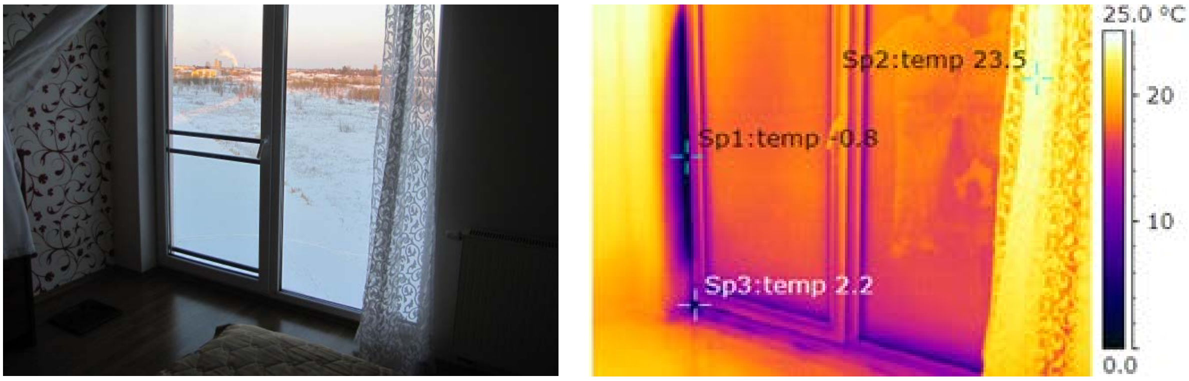

Figure 4. Leakages around the windows.

Figure 5. Air leakage between separating walls and the external wall.

Performance of ventilation

The performance of ventilation was assessed on the apartment level and on the bedroom level. Indoor climate category II (EN 15251: normal level of expectation and should be used for new buildings and renovations) was selected as reference.

Ventilation airflows in apartments were low in general (Figure 6) resulting in bad indoor air quality (Figure 7). Only in a few apartments did the general airflow correspond to the requirements of the indoor climate category II (>0.42 l/(s·m^2)). Even average general airflow (0.3 l/(s·m^2)) was below the indoor climate category II target value (>0.35 l/(s·m^2)).

Based on measurements of indoor CO_2 levels and estimated CO_2 (as tracer gas) emissions from residences during the night (≈20:00…8:00), the air change in bedrooms was estimated [11], Figure 8. As measurements were done in the main bedroom, the required airflow there should be at least 14 l/s. This average airflow was guaranteed only in 16 % of bedrooms during winter. Probably due to window airing during summer, this airflow was in 44 % of apartments.

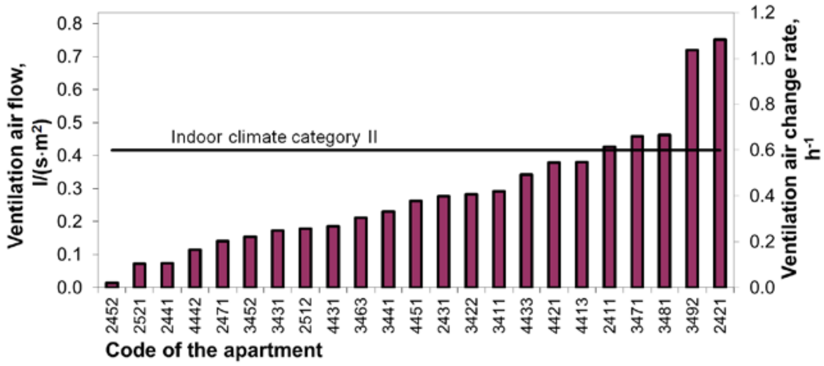

Figure 6. Ventilation airflow in apartments.

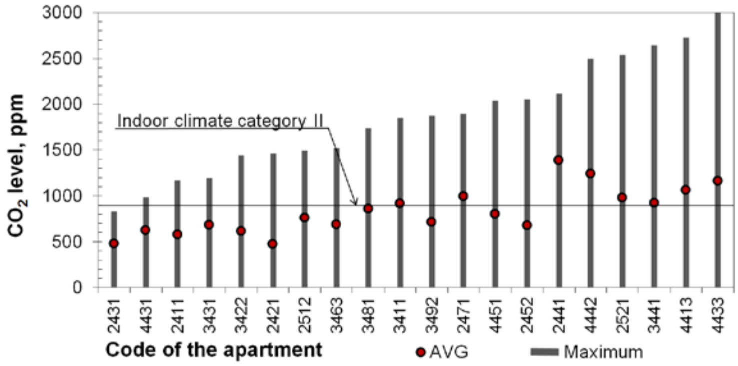

Figure 7. CO_2 levels in apartments.

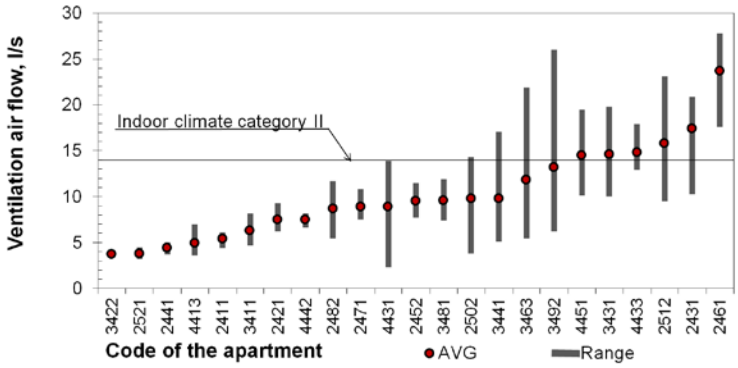

Figure 8. Ventilation airflows in bedrooms during winter.

DISCUSSION

The results of current study show that studied buildings are substantially more airtight compared to buildings from the period 1960-1990. About 92% of studied buildings satisfied minimum requirements for airtightness in Estonia (q_{50} < 3.0 $m^3/(h \cdot m^2)$). According to international standards on ventilation [14] and heating energy consumption [15], studied apartment buildings are buildings with low air leakage rates.

However, given the fact that according to the EPBD all new buildings must meet nearly-zero energy building’s requirements by the end of 2020, the Estonian building sector has a lot of improvement to do if the airtightness requirements will be changed, for example to level q_{50} < 1.0 $m^3/(h \cdot m^2)$).

Airtightness measurements showed small variations between newly built buildings with different structures, and large variations within similar structural solutions. For example air leakage rates of buildings made of prefabricated concrete elements were between q_{50} 0.82…4.55 $m^3/(h \cdot m^2)$, which clearly shows the impact of varied workmanship quality. Also typical air leakage distribution indicates that poor workmanship quality is behind the reason for low airtightness performance not low-grade building products. Airtight materials and good workmanship play important role in order to achieve high airtightness of building envelopes.

Due to larger air pressure differences over the building envelope in airtight buildings [12] and due to considerable moisture convection [13], special attention should be paid to the correct performance and balance of ventilation systems for ensuring a good indoor environment.

The performance of ventilation was not good in studied apartments. There was a very low correspondence for target values of indoor climate category II. The bad performance of ventilation is due to the extensive use of exhaust ventilation systems. In cold climates, taking outdoor air through the external wall without preheating does not provide thermal comfort (low temperatures, draft). If heat recovery is not used, it results in larger energy bills. These are the main two reasons why people decrease the ventilation airflows to the lower speed. If the exhaust fan is located in an apartment (bathroom, toilet, kitchen), then the noise may prevent the use of ventilation in a proper way.

CONCLUSIONS

The mean air leakage rate at the pressure difference of 50 Pa in the database was 1.7 $m^3/(h \cdot m^2)$, the minimum being 0.8 $m^3/(h \cdot m^2)$ and the maximum 4.6 $m^3/(h \cdot m^2)$. The mean air change rate at the pressure difference of 50 Pa from all the data was 2.3 h^{-1} (minimum being 0.9 h^{-1} and the maximum 6.6 h^{-1}). Based on the results it can be said that with all structural types it is possible to build airtight buildings, and quality of workmanship plays an important role in reaching a low leakage rate level. Future airtightness requirements may need improvement of current constructional style.

Together with the increase of the air tightness of building envelopes more attention should be paid to the performance of ventilation. The capacity of the ventilation system is not the only concern. Only increasing the ventilation airflow without proper design (noise reduction, avoiding draft, energy performance, etc.) may not guarantee good results.

AKNOWLEDGEMENTS

The research is done in project “Reducing the environmental impact of buildings through improvements of energy performance, AR12059” and has been financed by SA Archimedes. The study utilizes the measuring data of the national research projects financed by Estonian Credit and Export Guarantee Fund and by Ministry of Economic Affairs and Communications Research team of Chair of Building Physics and Architecture of Tallinn University of Technology is gratefully acknowledged for helping to carry out the measurements.

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