QUALITY OF VENTILATION SYSTEMS IN RESIDENTIAL BUILDINGS: STATUS AND PERSPECTIVES IN ESTONIA

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ABSTRACT

This paper focuses on the status and perspectives of the quality of ventilation systems of Estonian dwellings. The main topics focused on are the current indoor climate situation, installed products, design, installation, commissioning, maintenance, inspections and energy performance. Since the dwellings in Estonia can be divided into apartment buildings and detached houses, these types of buildings are studied separately. Field campaigns about the performance of ventilation in Estonian dwellings show that indoor air CO₂ is above allowed level and air change rate is too low to ensure good indoor air quality. Installed residential ventilation products are usually CE marked and supplied with necessary documentation. The dedicated education schemes for ventilation designers and installers are regulated with the professional standard. Main problems are associated with installation quality, ventilation control systems and service life maintenance. As the commissioning officers do not need to have HAVC area education, they have no competence to ensure the installation quality. Solution for these problems would be separate educational requirements for inspection officers and improvement of legislation in field of commissioning, maintenance and inspections. Also the energy performance calculations should be affected by the measured data and installation quality.

KEYWORDS

Indoor air quality, apartment buildings, detached houses, ventilation systems, installation quality

INTRODUCTION

Ventilation systems play important role in good indoor air quality (IAQ). IAQ is important, as most people spend significant part of their lives at home. In accordance with the requirements for dwellings [1] in Estonia, buildings must have natural or mechanical ventilation that guarantees the air change and circulation necessary for human activity. Air velocity in living spaces, the volume of the room per person and the content of harmful substances in indoor air must not exceed the values required. So, it is a legal obligation to install ventilation systems and to have good IAQ in dwellings in Estonia.

Even though IAQ is required, there are no official requirements for detailed criteria. National and international standards are used to determine detailed requirements.

This article looks at the current situation and guidance, rationale behind the approaches as well as their impact. The outcome of field campaigns is also shortly mentioned in the paper. It also follows the list of questions given by workshop organizers.

RESIDENTIAL VENTILATION MARKET

Dwellings in Estonia can be divided into two bigger groups: apartment buildings and detached houses (see Figure 1 left). The majority of apartment buildings are built after the second world war between 1950…1990 (see Figure 1 right).
The distribution of ventilation solutions in different periods in Estonian dwellings can be seen in Table 1. Older dwellings are equipped with natural exhaust ventilation, which means that stack for ventilation was built beside stack for stove chimney. The stove operated as a part of ventilation system, since air is needed for burning wood. Only very old dwellings (<1920) were built without stack for ventilation. Window airing was prevalent solution for that case.

Before 1991 almost all residential buildings were built without mechanical ventilation systems. Even if mechanical exhaust was designed, it made a loud noise while working and was therefore not used. Natural supply and exhaust (passive stack ventilation) is the dominant ventilation solution for dwellings, built before 1990. In rare cases they can be found later too, but this is more likely a design or constructional mistake. Natural supply was designed from air leakages, mostly through the windows. Fresh air inlets were sometimes used in case of apartment buildings.

<table>
<thead>
<tr>
<th>Type of ventilation system</th>
<th>Type of dwelling and construction period</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Detached houses</td>
</tr>
<tr>
<td>No ventilation</td>
<td></td>
</tr>
<tr>
<td>(window airing, no special stack for ventilation)</td>
<td></td>
</tr>
<tr>
<td>Natural supply and exhaust</td>
<td></td>
</tr>
<tr>
<td>(passive stack ventilation)</td>
<td></td>
</tr>
<tr>
<td>Natural supply and mechanical exhaust</td>
<td></td>
</tr>
<tr>
<td>Mechanical supply and exhaust with heat recovery</td>
<td></td>
</tr>
</tbody>
</table>

Table 1: Typology of ventilation systems in dwellings in Estonia.

Figure 2: The installation quality of old ventilation shafts is bad (left and middle) and filters of modern ventilation unit have become dirty (right).
After 1991, the use of mechanical ventilation started to increase, both for new and renovated buildings. The use of ventilation heat recovery began from ~2000 in detached houses and ~2010 in apartment buildings.

**Field measurements**
The last field campaigns about the performance of ventilation in new apartment buildings [2], [3] bring out that about 2/3 of apartments are equipped with mechanical exhaust ventilation (natural supply), see Figure 3 left. Ventilation airflows in apartments were low in general (see Figure 3 right). The general airflow corresponds to the requirements of the indoor climate category II (>0.42 l/(s·m²)) only in a few apartments. Even average general airflow (0.3 l/(s·m²)) was below the indoor climate category III target value (>0.35 l/(s·m²)).

![Distribution of ventilation](image)

Figure 3: Distribution of dwellings in subdivisions according to distribution of ventilation (left) and ventilation airflow (right).

Indoor CO₂ measurements showed high levels of CO₂ (see Figure 4 left) indicating bad indoor air quality. Based on measurements of indoor CO₂ levels and estimated CO₂ (as tracer gas) emission from residences during the night (≈20:00…8:00), the air change in bedrooms was estimated (see Figure 4 right). As measurements were done in the main bedroom, the required airflow there should be at least 14 l/s for II indoor climate category. This average airflow was guaranteed only in 26 % of bedrooms during winter. Probably due to window airing during summer, this airflow was provided in 44 % of apartments.

![Distribution of CO₂ levels](image)

Figure 4: Distribution of dwellings in subdivisions according to net area (left) and year of construction (right).

The main conclusion from field campaigns about the performance of ventilation in old apartment buildings [4], [5], [6] is that ventilation air flow rates are low in general. Improvement of ventilation (preferably supply-exhaust ventilation with heat recovery) together with improving thermal insulation of the building envelope, renovation and rebalancing of heating systems with thermostats equipped to the radiators, are necessary to provide the healthy indoor environment for the occupants.
PRODUCTS

According to Estonian Building Law [6] residential ventilation product characteristics should meet the requirements of European Harmonised standards. European Union construction products market is regulated by the EU regulation No 305/2011 (CPR) [8]. Estonian Building Law also notes that if there is no harmonised standard and then product characteristics should meet the requirements of technical acknowledgement of specific building product, technical acknowledgement of a member country of the European Union or technical acknowledgement of a member country of the European Free Trade Association (EFTA).

According to Estonian legislation there are more requirements for the documentation of residential ventilation products. Regulation nr 123 [9] establishes that the declaration of conformity must be provided to all construction products, for which there is a valid harmonized product standard, technical approval or which have been provided for safety. According to Estonian Building Law [7] the Certification Mark (CE) is demanded if it is required by standards. This mark guarantees the designer, installers and end users that products marketed by a participant have been accurately rated. Specification sheets, literature and advertising, should display the certification mark and the following statement. Directive 2010/30/EU [10] on the indication by labelling and standard product information of the consumption of energy and other resources by energy-related products is also compulsory.

Eurovent certification is sometimes required by the customer. This certification is voluntary but if the requirement has been written in ventilation project and required by the customer, it becomes compulsory. Eurovent certification helps to compare characteristics of ventilation products from different producers. As the certified data of certified models is listed in the Eurovent directory. Eurovent Standard is the best way to make the measures of the product characteristics available to designers and installers in a unified way. At the same time, the standard is required quite rarely and it has not turned into a norm.

Residential ventilation system manufacturers are aware of the role they play in the quality of installation. The documentation of products is usually composed based on the requirements of the European Union and Estonia. The main problem is the translation of the installation manuals into Estonian language like it is required in regulation no 123. Another issue is related to the quality of products. The most frequent problematic area is the noise level and automation system of products. Solving these problems is commonly the task of designers or installers. Manufacturers usually do not take any measurements and they are not responsible for the aforementioned problems. If there are problems with the residential ventilation product during the warranty time, the manufacturers usually solve these.

DESIGN

Education

According to Estonian regulations there is a certain education scheme for designers of ventilation systems. This educational scheme is explained in Estonian HVAC (heating, ventilation, and air conditioning) engineer professional standard [11]. The Professional standard is a document, which describes professional activities and also necessary skills that are needed by profession applicant or extender. The standard is composed according to The European Qualifications Framework (EQF). The EQF applies to all types of education, training and qualifications, from school education to academic, professional and vocational. According to the complexity of the work, the necessary know-how and the rate of autonomy and responsibility, the professional levels of HVAC engineers are defined by following:

- HVAC engineer (EKR Level 6);
- Certified HVAC engineer (EKR Level 7);
- Authorized HVAC engineer (EKR Level 8).
The punctual educational scheme for applying profession by the professional standard is described in Figure 5. First-time profession is termless, other professions, which are issued by the professional standard, last 5 years. Estonian Building Law [7] provides that the dedicated certification scheme covers the person. At the same time companies must have chief specialists who meet the requirements of HVAC engineer professional level.

Continuing education is a very important part of training schemes for designers. Before applying a profession of next level or extending the old profession it is necessary to pass a certain amount of continuing training points (TP). The educational scheme of continuing training is described in Figure 5. Continuing education trainings are organized by Tallinn University of Technology, Estonian Society of Heating and Ventilation (EKVÜ) and Estonian Association of Civil Engineers (EEL). A half day long training session gives 3 – 5 continuing educational points (TP).

Figure 5 Scheme for applying first-time professional levels of HVAC engineers (left) and applying the extension (right).

Requirements for ventilation systems
The ventilation systems of houses that were built before 1990 were designed by SNiP [13, 14]. At first the air exchange level in living rooms was 1 h⁻¹, later it changed to 3 m³/h. Exhaust air was removed from toilets, bathrooms and kitchens. Supply air was designed to enter through the cracks of windows and external walls.

At the beginning of the 1990s Finland designing norms part D2 [15] was used to design residential ventilation systems. The first Estonian standard for residential buildings, EVS 845-2:2004 [16] in year 2004, was also composed according to Finnish standards. Indoor environmental input parameters standard [17] was taken into use in 2007. At the present moment CEN/TR 14788 [18] is also valid but it is not widely used in practice. Most of the designers still use ventilation airflow norms from EVS 845-2:2004 or from Finnish norm D2. The historic overview of Estonian ventilation standards and norms is given in Table 2.

In Estonia the indoor air CO₂ concentration is considered in the standard of the indoor environmental input parameters [17] and designing criteria CR 1752 [19]. The parameters are described in Table 3.

Although residential ventilation system designers are usually aware of the role that they can play in getting the best possible result, they have difficulties in influencing the quality of installation. The only possible way to increase the quality of installation is designing ventilation systems that are as good as possible and to write the quality standards in the ventilation project. Estonian residential ventilation system designers usually do not take measures of the systems they have designed. Since they do not know the final result of the installed ventilation system, they often
repeat the same mistakes in their future projects. To improve the designing quality it would be useful to take the measures after the installation.

<table>
<thead>
<tr>
<th>Time period</th>
<th>Standard</th>
<th>Supply air</th>
<th>Exhaust air</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Living room</td>
<td>Bathroom</td>
</tr>
<tr>
<td>- 1991</td>
<td>CHHiIT-II-J1.1-71</td>
<td>1 h⁻¹ (earlier)</td>
<td>7 l/s (75 m³/h)</td>
</tr>
<tr>
<td></td>
<td>CHHiIT 2.08.01-85</td>
<td>0.8 l/(s-m²)</td>
<td>7 l/s (25 m³/h)</td>
</tr>
<tr>
<td>1991 – 2000</td>
<td>Finnish NBC-D2</td>
<td>or 0.7 l/s/m²</td>
<td>10 l/s (54 m³/h)</td>
</tr>
<tr>
<td>(still used)</td>
<td></td>
<td>4.0 l/(s-pers) or 0.7 l/s/m²</td>
<td></td>
</tr>
<tr>
<td>2000-2007</td>
<td>EPN18.3.2/EVS</td>
<td>0.5 l/(s-m²)</td>
<td>15 l/s (54 m³/h)</td>
</tr>
<tr>
<td>(still used)</td>
<td>845-2:2004/</td>
<td>0.7 l/(s-m²)</td>
<td></td>
</tr>
<tr>
<td>2007-</td>
<td>EVS-EN 15251:2007</td>
<td>20 l/s</td>
<td>10 l/s</td>
</tr>
<tr>
<td></td>
<td>350, ppm</td>
<td>IC category II: 7 l/(s-pers)</td>
<td>IC category II: 10 l/s</td>
</tr>
<tr>
<td></td>
<td></td>
<td>IC category II: 7 l/(s-m²)</td>
<td>IC category II: 15 l/s</td>
</tr>
<tr>
<td></td>
<td></td>
<td>IC category III: 4 l/(s-pers)</td>
<td>IC category III: 14 l/s</td>
</tr>
<tr>
<td></td>
<td></td>
<td>IC category III: 0.6 l/(s-m²)</td>
<td>IC category III: 10 l/s</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.0 l/(s-m²)</td>
<td>IC category III: 7 l/s</td>
</tr>
<tr>
<td>2006-</td>
<td>CEN/TR 14788</td>
<td>3…5 l/(s-pers.)</td>
<td>approx. 15 l/s</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.5…7.5 l/(s-pers.)</td>
<td>approx. 10 l/s</td>
</tr>
</tbody>
</table>

Table 2: Residential ventilation norms and standards in Estonia [13], [14], [15], [16], [17], [18].

<table>
<thead>
<tr>
<th>Indoor climate category</th>
<th>Expected percentage dissatisfied, %</th>
<th>CO₂ concentration at outdoor air level 350, ppm</th>
<th>Indoor air CO₂ concentration, ppm</th>
</tr>
</thead>
<tbody>
<tr>
<td>I (A)</td>
<td>15</td>
<td>460</td>
<td>810</td>
</tr>
<tr>
<td>II (B)</td>
<td>20</td>
<td>660</td>
<td>1010</td>
</tr>
<tr>
<td>III (C)</td>
<td>30</td>
<td>1190</td>
<td>1540</td>
</tr>
</tbody>
</table>

Table 3: Class of the indoor climate for rooms with human activity [19].

**INSTALLATION**

According to current professional standard of Estonia [20] the qualification requirements of ventilation system installers are determined in 3 levels. The profession of ventilation and environmental technology locksmith can be acquired in 5 Estonian Industrial Schools. In-service training for ventilation locksmiths is not organized. Approximately 75 % of ventilation installers do not have any professional preparation at all.

The quality of installation might influence the energy performance calculation. The main cause for that is the fact that installation companies attempt to change the project solution and material for cheaper replacements. In practice these uncoordinated project changes might influence the energy calculation. The most common requirement is that the installation of residential products should be done by the installation manuals of specific products. Instructions can also be found from Estonian standards and from different quality requirements. The valid quality regulation is Estonian RT catalogue, which was taken over from Finnish LVI RYL [21]. Electrical installation of residential products should be done by Directive 71/305/EEC [22]. The most important requirement is that the installation should follow good building traditions. Good building traditions are based on valid standards and quality regulations.

According to Estonian Building Law [7] installer must provide the customer with the following documentation:
- Building project and it’s changes;
- Works diary;
- Acts of covered works;
- Protocols of working meetings;
- Other documentation like as-built drawings and certifications of conformities.
Residential ventilation system installers are aware of the role that they can play in the quality of the installation. The main purpose why they withdraw the level of quality is the desire to decrease the cost of the solution. At the same time installers also find mistakes in designer’s work from time to time. In this case the only solution is to find the best possible solution in collaboration with the designer and the installer. Ventilation installer must give a protocol of measurements to customer and supervisory. According to Building Law [7] it is not possible to get the certificate of occupancy before providing the protocol of measurements. Regulation No 75 [23] defines the requirements to protocol of measuring. Measures should always be done by a company that has rights to measure ventilation systems.

COMMISSIONING
Commissioning is compulsory in case of residential ventilation systems. The demand of commissioning comes from Estonian Building Law [7] and Estonian Regulation no 11 [24]. Before the start of the building process the owner of the dwelling has to determine a certified company. In case of detached houses the owner has the right to carry out the monitoring. Compulsory commissioning is also carried out by the commissioning specialist of local authority. According to regulation no 11 [24] local authority must perform commissioning before giving the certificate of occupancy. Based on the regulations, it is necessary to control the following points during the commission:
- Does the building meet the requirements;
- Does the building project and measuring protocol meet the requirements;
- Does the technical documentation meet the requirements.

Measuring protocols must include the measurements of airflows and sound levels generated by the ventilation. Ventilation airflows must be compared with the project values. Permissible deviation compared to the designed levels is ±20 % in case of air terminal devices and ±10 % in case of ventilation unit. By the requirements for dwellings [1] the level of sound pressure in living spaces is not allowed to exceed 40 dB(A) in daytime and 30 dB(A) in night time.

There are no dedicated educational or training schemes for residential ventilation systems commissioning. Dedicated certification for residential ventilation commissioning also does not exist. As the regulations do not demand special education in field of HVAC, the commissioning specialists are often not competent and might accept lower installation quality and extensive replacements in comparison to the initial project. The solution for this problem would be to develop the dedicated training schemes for commissioning and demand the special education in the field of HVAC.

MAINTENANCE
According to Estonian standard EVS 830:2003 [25] and ordinance no 55 (Fire Safety regulations) [26] ventilation chambers, air filters, and air ducts are cleaned from combustible dust and from burning material by the schedule of the owner. Ventilation systems should not be cleaned less than once a year. Unless the maintenance instruction manuals of a ventilation product demand more frequent maintenance, then maintenance should be done according to product guidelines. Maintenance works of ventilation system can be divided into 4 groups [25]:
- Everyday maintenance (or short period maintenance);
- Regular maintenance to find out the problems;
- Main maintenance (yearly maintenance);
- Maintenance based on official regulations.

The main content of the maintenance is changing the filters of ventilation units. It is recommended to change the filters 2 times a year, in autumn and spring. In addition to the filters it is also important to ensure the purity of ventilation ducts. The recommended value for level of
purity is $P_1 \leq 0.7 \text{ g/m}^2$ [27]. To make the cleaning of the ventilation system possible it has to be equipped with cleaning hatches. It is also important to do maintenance for other parts of ventilation system.

In detached houses maintenance is mainly done by occupants. In apartment buildings it is also done by special maintenance companies or by the maintenance specialist of housing association. The most common situation is that maintenance is not done at all or done only in case the problem has already taken place. It is quite common that ventilation systems do not operate properly or are switched off. There are no dedicated education schemes, training schemes or labelling schemes for residential ventilation systems maintenance. To overcome these problems it is important to improve the regulations of ventilation systems maintenance. One more opportunity would be to improve the educational schemes for ventilation systems maintenance.

**INSPECTIONS**

For residential ventilation systems there are no mandatory inspection schemes. Usually inspections take place as a part of the change of ownership of real estate or on request of insurance. The process of property evaluation is regulated by Estonian standard EVS-875 [28]. In a field of residential ventilation, inspections are generally not done by a professional. This is the reason why ventilation problems are left aside. Residential ventilation systems are also inspected during energy audits. Usually energy audits give recommendations to decrease the energy consumption and to improve the IAQ. Recommendations for ventilation renovations are usually one part of energy audit.

According to the Estonian Building Law [7] the results of inspections are carried to the Estonian Building Register. There are no dedicated education schemes, training schemes or labelling schemes for residential ventilation systems inspections. The first thing to do in order to change the present situation in the field of inspection is to work out pertinent regulations of ventilation systems inspections.

**INFLUENCE OF THE QUALITY OF VENTILATION SYSTEMS ON THE BUILDING ENERGY PERFORMANCE ASSESSMENT REDITS AND PENALTIES**

Minimum requirements for energy performance of buildings are determined with Estonian Government Ordinance No. 258 [29]. The energy performance calculation is not affected by the measured data or installation quality. At the moment there are no credits or penalties linked to the quality of residential ventilation systems.

<table>
<thead>
<tr>
<th>Topic</th>
<th>Major causes of quality problems</th>
<th>Existing quality schemes or incentives</th>
</tr>
</thead>
<tbody>
<tr>
<td>Product</td>
<td>Products control systems are not working properly, product documentation is not translated into Estonian</td>
<td>yes: EU regulation No 305/2011, Governmental orders and laws</td>
</tr>
<tr>
<td>Design</td>
<td>no consideration of noise levels, no ventilation sound attenuators between the apartments, ventilation units are designed on max speed</td>
<td>yes: residential ventilation standards, Governmental orders and laws</td>
</tr>
<tr>
<td>Installation</td>
<td>The quality of installation is bad, installations are not made by the ventilation project</td>
<td>yes: Finnish LVI RYL, by EVS-EN 60947-1:2001/A2:2002, Directive 71/305/EEC</td>
</tr>
<tr>
<td>Commissioning</td>
<td>Commissioning specialist is not specialist in a field of ventilation,</td>
<td>yes: Estonian Building Law, Governmental ordinance nr 11</td>
</tr>
<tr>
<td>Maintenance</td>
<td>Maintenance is not done by the regulations and product guidelines</td>
<td>yes: EVS 830:2003, Governmental ordinance nr 55</td>
</tr>
<tr>
<td>Inspections</td>
<td>No regulations</td>
<td>no</td>
</tr>
</tbody>
</table>

Table 4: Summary of problems observed regarding the quality of residential systems and schemes that have been implemented or that are under development to overcome these problems.
CONCLUSION
As the design and installation quality of ventilation systems plays an important issue in energy performance of buildings it is very important to ensure the best possible solutions. The most important problems of residential ventilation systems are associated with duct and ventilation material installation quality and project changes without consulting ventilation designer. The legislation is quite sufficient in case of products, design and installation. Legislation should be improved in field of commissioning, maintenance and inspections. The energy performance calculation is not affected by the measured data or installation quality. But there are also problems with ventilation control systems and service life maintenance. As the commissioning officers do not need to have HAVC area education they have no competence to ensure the installation quality. Solution for these problems would be separate educational requirements for inspection officers and improvement of legislation in field of commissioning, maintenance and inspections. Also the energy performance calculations should be affected by the measured data and installation quality.

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