QUALITY OF VENTILATION SYSTEMS IN RESIDENTIAL BUILDINGS

STATUS AND PERSPECTIVES IN BELGIUM

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ABSTRACT
After some general information on the Belgian residential ventilation market, various field campaigns are discussed. These studies reveal the existence of various problems in the residential ventilation installations. Indoor air quality problems are reported, as well as other problems that are linked to poor design, poor installation work, poor commissioning and poor maintenance.

With regard to products, the main problem isn’t the quality of the product on its own, but often the absence of reliable product data. The key issue to improve the situation is to increase the professionalism when designing, installing and commissioning ventilation systems. Apart from product declarations and training actions for various professional levels, a voluntary quality scheme is under development in which an onsite compliance check is crucial. This compliance check will refer to clear and verifiable system performance criteria, whereby involvement and cooperation of different market stakeholders is crucial.

KEYWORDS
Ventilation criteria, Indoor Air Quality (IAQ), quality scheme.

INTRODUCTION
In the past decade the demands on energy performance of buildings have strengthened. As a result of this the need to incorporate designed ventilation systems into dwellings has increased and is often imposed by legislations. As buildings become more airtight, the IAQ and indoor humidity is more sensitive to ventilation system design, sizing and installation errors. Field studies show evidence that installation quality of residential ventilation systems is often insufficient. Therefore more attention should be paid to ventilation system performance, installation quality and maintenance, in order to guarantee healthy indoor environments. This paper gives an overview of the situation in Belgium with regard to the quality of residential ventilation systems.

RESIDENTIAL VENTILATION MARKET
This paper concentrates on small residential ventilation systems in Belgium, which are normally designed and installed by architects, small installation companies also dealing with other techniques or do-it-yourselfers. This market also includes small non-residential ventilation systems (with capacities up to 500-1000 m³/h) as for small shops or physician cabinets. Centralized ventilation systems in multi-family houses or apartment buildings are excluded from this discussion, as they can be pretty different from a technical point of view and are dealt with by specialized engineering companies and installers.
Securing the quality of ventilation systems in residential buildings

Although a Belgian standard exists since 1991 (ref. [11]), this was mandatory in only one of the 3 Regions of Belgium since 1996. In 2006 and 2008, the EPBD-legislation (Energy Performance of Buildings Directive) came into force in all the 3 Regions of Belgium that makes the installation of a ventilation system in newly built houses mandatory. The ventilation requirements are included in this EPBD-legislation. There is no obligation to install a whole ventilation system in refurbishments, nor in existing dwellings; only when windows are refurbished during a renovation for which a building permit is needed, does the EPBD-legislation require to install at least an outdoor air supply.

For information, we should clarify the situation in Belgium a bit. Although a lot of legislation is valid on the federal level (the whole country), energy related issues, including ventilation, are dealt with by the 3 Regions: Flemish Region, Walloon Region, Brussels capital Region. Although details and date of coming into force might differ, the main content for energy issues is very similar for the 3 Regions.

The legislation refers mainly to the before mentioned standard and defines the ventilation capacity of outdoor air for supply (generally 3.6 m³/h per m² floor area) in so-called dry spaces (habitable rooms such as living area, bedrooms, study,...) as well as the ventilation capacity for exhaust in so-called wet spaces (kitchen area, bathroom, laundry,...). Air transfer openings with a free section of 70 cm² in at least one internal door per room (140 cm² for the kitchen) are needed.

4 different ventilation systems are allowed:
- System A: natural supply and natural exhaust
- System B: mechanical supply and natural exhaust
- System C: natural supply and mechanical exhaust
- System D: mechanical supply and mechanical exhaust (with or without heat recovery)

Generally speaking, the standard and the legislation are rather descriptive, little performance based criteria are included. Demand controlled ventilation may be applied to all of these systems.

For the Flemish Region, some detailed information is available for the market share of the 4 systems in newly built dwellings and apartments, also indicating the evolution thereof from 2006 to 2010 (ref. [1]). As can be deducted from Figure 1, in dwellings mainly mechanical exhaust systems (C) and all mechanical systems (D) are installed in 2010. For apartments some 10% of the systems are all natural (A). Mechanical supply systems (B) are hardly used in both dwellings and apartments.

Although exact data are missing, one can assume that nearly all ventilation systems D include air to air heat recovery. The same trends are probably also valid for the 2 other Regions of Belgium.

For the existing building stock, data are missing. One can assume that dwellings built before the entry into force of the EPBD-legislation (2006-2008) hardly have any ventilation system, with the exception of some fans in toilets or a cooking hood in the kitchen. Even in the Walloon Region with a previous obligation since 1996, the effective installation of ventilation systems was limited before the EPBD-legislation, mainly due to the lack of enforcement. Important refurbishments of dwellings might contain ventilation systems, but to a much lower extent than in newly built houses, because of the lack of legislation.
Compliance checks in the field are done by the authorities on a very marginal case-to-case basis. However, the energy performance legislation in Belgium requires a declaration of the as-built situation once the construction is finished. This declaration must be done by a mandated person and includes all the reported ‘as built data’ used in the energy performance calculation. For ventilation this includes elements such as design flow rates and fan electricity consumption. There is no strict obligation to measure the performance of the system, e.g. actual air flow rates and duct leakage. For some of these elements, there are default values which are quite unfavourable and it is not mandatory to report more detailed values. However, a number of system characteristics, if reported and proven, can lead to a better result of the so-called E-level (the calculated indicator of building energy-performance, used in Belgium) than those using the default values. This E-level should not exceed a defined level, and some financial support might be obtained for lower (better) figures.

In the past years, some field campaigns have taken place by research institutes to investigate the actual quality of the ventilation systems in dwellings. A short overview is included in the background chapter at the end of this paper.

**PRODUCTS**

In the Belgian legislation, there are hardly any additional product requirements for ventilation components, in addition to the EU product Directives (Low voltage Directive; Ecodesign Directive, not yet into force). A certified technical approval (called ATG) is possible to certify some product characteristics on a voluntary basis (based on European standards or specific guidelines), but no approved products are available on the market for ventilation.

In order to complete the EPBD declaration, a number of characteristics of products used in the project need to be reported. Needed product data are e.g.: flow capacity of natural ventilation openings, type and power of fans, temperature effectiveness of heat exchangers,... Because some doubt can exist on behalf of the data supplied by the manufacturer, products can be recognized in a database ([www.epbd.be](http://www.epbd.be)), managed by an independent operator. To be
recognized in this database, the products should be measured according to dedicated standards and specific procedures. Notwithstanding the notification in this database is fully voluntary, many products are already recognized. The main advantage is the higher reliability of the recognized data thanks to a robust compliance framework (verification by an independent third party, well described and uniform methodology). It is however important to indicate that this approach doesn’t appreciate the quality of the products (no performance limits are fixed, no durability evaluation, only initial type testing without follow up of the production,...).

Generally speaking, there is no main quality problem with the products as such. Problems arise mainly due to inappropriate selection of products in the design phase. This is reflected for instance in the fan power of installed residential systems measured in the Optivent survey (Figure 2). Although high efficiency products are available, large performance variations are found in installed systems. System manufacturers are aware of this problem and show some attempts to inform or help the installers. Some suppliers offer ventilation kits that perform an automatic start up cycle in which the flow rates are set automatically to the required flow rate, regardless the duct length (within the defined margins). Some manufacturers work also (only) with installers recognized and trained by the manufacturer itself.

A specific assessment procedure exists for demand controlled residential ventilation systems, which are considered as ‘innovative’ systems in the framework of the EPBD-legislations in Belgium. For these systems ‘principle of equivalence’ procedures have been developed, in order to allow the assessment of systems not covered by the standard calculation procedures. The performance based approach used in the assessment applies numerical air flow models and Monte Carlo analysis in order to predict the IAQ and ventilation heat loss associated with a specific demand controlled system. The simulations use the test characteristics of system components as an input (e.g. flow and fan characteristics, control functions and algorithms). The results are compared to the performances of standard ventilation systems to establish the ‘equivalence’ of the innovative system and to characterise its energy performance. In total 14 systems from 8 manufacturers have received a ‘declaration of equivalence’ from the regional authorities up to now. (http://www.energiesparen.be/epb/prof/gelijkwaardigheid)

![Figure 2: Measured specific fan power (SFP) for residential all mechanical ventilation systems at nominal flow rate (Caillou 2011)](chart.png)
DESIGN, INSTALLATION AND COMMISSIONING
Unless for big, non residential ventilations systems where the tasks design, installation and commissioning are dealt with by engineering companies, specialized installation companies and independent commissioning and control organisms, these tasks aren’t dissociated the same way in small residential installations. Therefore we treat these activities in one chapter only.

For residential ventilation systems, the guidelines defined by the architect are mostly limited to some general requirements (type of ventilation system, position of air terminal devices or ventilation unit,...). They follow the prescriptive rules laid down in the legislation and standards, in which little performance based criteria are included. Most of the detailed design activity (flow rates, sizing of the distribution network, component selection, control,...) is done by the installation company. These companies are commonly small and conduct also other installation activities such as heating, sanitary appliances, electricity. Frequently they are not specialized in ventilation systems only. This problem already starts with education: the profession “installer of ventilation systems” doesn’t really exist in Belgium yet. For a part this is due to the historical context (ventilation systems in dwellings hardly existed before 2006); on the other hand, a ventilation system nearly always contains aspects to be realized by various specialities: ventilation system installer, but also a carpenter, mason or roofer.

During high school education of technical profiles, ventilation system design and installation is only treated to a limited extent (as a part of the education for heating or sanitary installer). During the education of architects and civil engineers, the design of ventilation systems is part of the training in designing and sizing HVAC-systems. For residential systems the information is often limited to the prescriptive standards. The training of mechanical engineers focuses on ventilation components (fans, heat exchanger design), but to a much lower extent on system design. The extent of the training might depend on the institute and the accents of individual teachers.

Actually, more attention is given to training schemes for professionals already active in the ventilation business. Professional societies for architects and engineers regularly organise general training sessions about ventilation, however without going into detail and without the practical aspects of calculating and installing, commissioning,...

For installers, continued education institutes organise extended training courses for ventilation (typically 30 hours). We feel these courses show a lack of consistency between different regions. Contents and quality depend a lot on the trainer himself. Overall training schemes, supported and approved by the sector don’t exist yet.

The result of all this is that the quality of the installation, expressed in measurable properties such as compliance of flow rates with design and airtightness of duct systems is frequently below expectation (Figure 3).

What, in our opinion, is needed to improve this situation includes:
• Establish criteria for the ventilation systems that are clear and can be verified on the ‘as installed’ system. Basically, they should be performance based in order to give design freedom and stimulate innovation, but when this isn’t appropriate or feasible, they can be replaced by prescriptive rules. As a minimum they require the conformity with legal requirements, but they can go far beyond. Apart from technical requirements, the need for a well documented commissioning; the supply of occupant information as well as user manuals and maintenance information is foreseen in these criteria.
A sector agreement is important. Requirements according to NBN and EN standards are a starting point, but need to be enlarged. BBRI-Quest (Quality centre for sustainable energy systems) made a start with this task (ref [11]). These criteria can change as function of time and should follow market development.

- Establish practical guidelines that enable to design, install, commission and maintain the ventilation systems in a way they respond to the above mentioned performance criteria. This requires the availability of codes of good practice, calculation tools, measuring and adjustment methods,... Existing guidelines from BBRI (ref [3] and [3]) are being updated and completed with tools, close to practical implementation.

- Define education schemes on various levels: architect and design engineers, installers (as the responsible person for the installation company), technicians and labourers. Unified education schemes are needed, complete with training syllabi, presentation modules and practical training sessions, as well for design as for installation, commissioning and maintenance. At this moment a roadmap is under development regarding training issues for technicians and labourers within the project ‘Build up skills Belgium’ and FVB-FCC\(^1\).

- Set up a methodology to check the compliance of the installation with the above mentioned quality criteria. Three approaches, that can coexist in parallel, are under consideration:
  - Compliance checks of each installation by a third party (independent) specialist. These experts themselves should be trained and certified
  - Compliance is checked by the certified installation company itself or a certified person within the company.
  - Compliance is checked by a certified overall quality approach of the company (ISO 9001 alike).

Actually, the first 2 approaches are under development.

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\(^1\) FVB FCC Constructiv: Fonds voor vakopleiding in de bouw: Organisation for training of construction labourers
OPERATION AND MAINTENANCE
Reference documents as well as product documentation normally contain operation and maintenance instructions. They might differentiate the maintenance between activities by the user or by the installer. However a number of problems exist:

- Maintenance instructions are often very general, and are not very clear about the real interval to be applied, about the need for cleaning or replacing filters,...
- Even if information is available in the product documentation:
  - It might not be handed over to the end-user, nor explained
  - It is limited to the individual product and not made specific to the as-built situation as a combination of various products. E.g. for fan speed control it is well explained that 3 positions are available, but not at what speed they should be operated, nor in which conditions (absent, normal use, party use,...).
- Organizing maintenance, to be done by the end-user or by a professional, is left over to the owner or occupant. In a lot of cases, nothing is done at all.

Currently, there aren’t any mandatory requirements on maintenance of residential ventilation systems, as is the case with certain heating installations. Up to our knowledge, nothing is planned so far.

Because of the lack of adequate reference documents, occupants are usually ill-informed about the required flow rates for their situation and tend to operate the ventilation system continuously at low flow rates, or close natural ventilation openings almost continuously. The main reasons reported for this are acoustical problems (Figure 4) or draught at high air flow rates and the desire to save energy. Users are able to operate their systems at lower flow rates, because it is mandatory in legislation that ventilation systems are adjustable.

INSPECTIONS
With regard to inspection before putting the ventilation system into service, this is an integral part of the installation and commissioning, already discussed in the chapter "Design, Installation and Commissioning". Although it could be useful to inspect each residential ventilation system after a certain time in operation (3, 10 or more years?), at this moment,
nothing is available or customary. In case of inspection by the installation company itself, this
could be done in combination with regular maintenance, if performed. When a more
independent inspection would be required, similar certification schemes as for installation
companies might be appropriate (fully independent or company under certification).

INFLUENCE OF THE QUALITY OF VENTILATION SYSTEMS ON THE
BUILDING ENERGY PERFORMANCE ASSESSMENT: CREDITS AND
PENALTIES
As explained in the first chapter, a number of ventilation system characteristics may affect the
EPBD-calculation. Some of them are mandatory data, other characteristics are voluntary data.
When not introduced, (more unfavourable) default values will be used to perform
calculations.

Characteristics that might be reported on a voluntary basis are e.g.: measured air flow rates
and balancing, low power fans, heat recovery effectiveness, duct leakage, demand control
add-ons,... Some examples:

- Product-wise: when balanced mechanical ventilation systems are not equipped with an
  automatic control of supply and exhaust flow rates, the heat exchanger effectiveness is
  reduced by 10%.
- Installation-wise: when measured flow rates at commissioning are shown to be within
  a defined % of the required flow rates, the ventilation heat loss in the EPBD-
  calculation is reduced by 10-20%, depending on the system.

At this moment, little control exists on the quality of the obtained values: e.g. measured flow
rates can lead to a better performance. However, the measuring conditions aren’t described
well although we know airflow measurement is not a straightforward issue.

BACKGROUND CHAPTER: ADDITIONAL FIELD CAMPAIGNS

“OPTIVENT” project
- Period: 2011
- Quantity: over 40 dwellings
- Flemish and Walloon Regions
- Main objectives: air flow rates, fan electricity consumption, microbiological
  conditions, acoustical nuisance, on site heat recovery efficiency

More than 40 ventilation systems in dwellings have been, at least partially, monitored. Most
of them are installed in recent buildings but some are in use since several years, up to 16
years. They are mainly all mechanical systems, but also some systems with natural supply and
mechanical exhaust have been evaluated.

The total air flow rate in the dwelling is in general sufficient but the repartition of the flow
rate in the different rooms is usually very poor, showing possible improvements thanks to a
correct adjustment of the ventilation system.
The electricity consumption in the samples vary for a very large extent from 0.24 to 0.90
W/(m²/h) for all mechanical systems, demonstrating the huge potential of energy savings by
the choice of fan and duct type and by the correct dimensioning of the ductwork.
The real heat recovery effectiveness has been evaluated continuously, showing in some cases
a similar performance as obtained in laboratory tests, but also revealing some critical points
for heat recovery in practice, such as flow balance, control of the by-pass, etc.
The measured noise levels are usually too high, but the comparison of the measured levels with the solutions used for the design and installation allows to identify the most important attention points for a better acoustical comfort.

Finally the microbiological results demonstrated that well-designed and maintained ventilation systems present no additional microbiological risk compared to outdoor air. Ventilation systems with supply air filtration are able to significantly decrease the amount of micro-organisms from the outdoor air. The results also highlight the critical point to limit the microbiological risk of ventilation systems: maintenance of the filters (for example replacement once a year), position of air intake to avoid recirculation of polluted air, etc.

**“CLEAN AIR LOW ENERGY” project**
- Period: 2011-2012
- Quantity: 25 dwellings
- Flemish Region
- Main objectives: air flow rates, building airtightness, chemical air pollutants, microbiological conditions, acoustical nuisance

All monitored systems are installed in recently built dwellings, dating from 2006 or later. 3 dwellings were equipped with exhaust ventilation, while the remaining 22 were fitted with heat recovery ventilation. In each house, the flow rates in normal operating conditions were measured, and in more than half (16) of the cases, the maximum capacity at the air terminal devices was also assessed. Acoustical performance was only measured in a subset of cases. For each dwelling, a pressurisation test was executed to determine the leakage level of the building envelope.

In none of the dwellings with heat recovery ventilation, the design flow rate was achieved in all spaces. 4 dwellings with heat recovery ventilation achieved a total supply flow rate equal or greater than the total design flow rate. The average of the ratio between these two flow rates was 0.75. In only one of the three cases with mechanical exhaust ventilation, the total extraction flow rate met the required total design flow rate. The ratio of total exhaust flow rate and design flow rate for these cases was on average 0.52.

Measured installation sound levels for heat recovery ventilation were too high compared to the levels required by the building code in 70% of the spaces at full capacity. The majority of the systems however operated within ‘high acoustical comfort’ conditions at the intermediate flow rate. Exhaust ventilation cases seem to perform slightly better, but these were much more sensitive to ambient noise.

Regarding exposure to pollutants, the study concluded that the physico-chemical quality of the indoor air in energy-efficient, mechanically ventilated houses was found to be moderately improved or equal to the indoor air quality monitored in previous campaigns in traditional buildings without ventilation systems.

**UGENT campaigns**
- Period: 2009-2012
- Quantity: 53 dwellings
- Flemish Region
- Main objectives: air flow rates, building air tightness

A number of field campaigns were undertaken by UGent to investigate the quality of ventilation systems in Flemish single family dwellings, built between 2006 and 2009, complying to the EPBD-requirements. Most of these dwellings had a mechanical exhaust system (81%), a limited share had balanced mechanical systems (15%).
The design and installation of exhaust ventilation systems were found to be in reasonable good agreement to the design flow rates required in legislation. Overall about 70% of the natural ventilation openings and transfer openings had a correct sizing, but only 40% of the mechanical exhaust rates were sufficient. However in 80% of the dwellings the total exhaust flow rate per dwelling delivered the minimal design flow rate within 25% (Figure 5), but with a poor adjustment of flow rates within individual rooms.

For balanced mechanical systems similar findings were determined in terms of exhaust flow rates and transfer openings. However mechanical supply rates were typically insufficient, certainly in living rooms, where none of the investigated systems was able to deliver the minimal flow rates.

Figure 5: Measured total mechanical exhaust rates per dwelling, compared to minimal values in legislation. The bars reflect the measured exhaust flow rates at different positions of the fan control switch. (UGent campaign)

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<th>Topic</th>
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<th>Existing quality schemes or incentives</th>
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<td>Available for some products, no further actions planned in the short term</td>
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<tr>
<td>Design</td>
<td>In most cases, insufficient design is performed (rules of thumb)</td>
<td>Quality scheme under development that requires design documentation and as installed performance based requirements</td>
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<tr>
<td>Installation</td>
<td>Insufficient design available, with as a result undersized systems, noise problems,...</td>
<td>Quality scheme under development that requires as-installed performance. Some manufacturers employ certified trained contractors</td>
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<td></td>
<td>Ad hoc design modifications Cleanliness of duct system</td>
<td></td>
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<tr>
<td>Commissioning</td>
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<td>Quality scheme under development that requires as-installed performance, proved by commissioning In energy performance legislation commissioning is encouraged (ventilation flow rates, balancing of supply and exhaust,...)</td>
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Table 1: Summary of problems observed regarding the quality of residential ventilation systems in Belgium and schemes that have been implemented or that are under development to overcome these problems.
CONCLUSION
Generally spoken, the problems that arise in ventilation systems in dwellings are widespread and well known. Fortunately, technical solutions to overcome these problems are known. Various actions are planned in order to facilitate the application of these solutions in reality, onsite. A market supported time schedule is needed now to enhance implementation.

Table 1 inventories the major causes of quality problems and indicates running or planned actions to improve the situation. The energy authorities in the Flemish Region (VEA - Vlaams Energieagentschap) initiated a project to evaluate the willingness to introduce a quality approach for ventilation systems (VEA 2012).

Without looking too much ahead, following approaches might be withheld:

- Reinforce ventilation quality aspects into the EPB-legislation and the energy performance calculation. It doesn’t seem to be realistic to increase the application control by the administration itself, but a link with a declaration of conformity might be made.

- Make training available for various professional levels: architects, installers, craftsmen and performance evaluators.

- Organize a system to deliver a declaration of conformity for each installation. This approach declares for each individual installation:
  - The conformity with the legal or additional performance requirements.
  - All relevant data enabling to calculate the ventilation aspects in the energy performance calculation: product performances such as flow rate capacities, auto-control capacities, fan power,… or system measurements such as measured flow rates.

REFERENCES


[14] VEA 2012, Vlaams Energieagentschap (Flemish Energy Agency), Bestek VEA/EPB/2012/KDB/1, Studie betreffende het onderzoek naar een draagvlak voor het invoeren van kwaliteitsseisen voor ventilatievoorzieningen (in Dutch: Bid for a study concerning a basis for the introduction of quality requirements for ventilation systems).