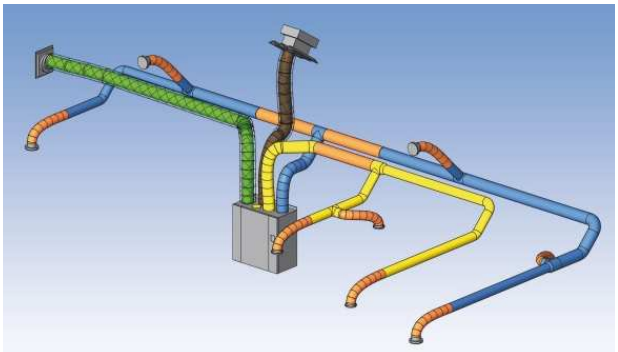
International workshop
Brussels, 18-19 March, 2013

Securing the quality of ventilation systems in residential buildings



Existing approaches in various countries

An initiative of AIVC, TightVent and INIVE EEIG

edited by A. Janssens (UGent), F.R. Carrié (INIVE EEIG) and F. Durier (CETIAT)

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Securing the quality of ventilation systems in residential buildings: existing approaches in various countries

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- Ventibel (Sector organisatie voor ventilatie – Fédération pour le secteur de la ventilation) (www.ventibel.be)

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PREFACE

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IMPROVING THE QUALITY OF RESIDENTIAL VENTILATION SYSTEMS

While it is generally accepted that ventilation -whether natural, mechanical or hybrid- is needed to provide acceptable indoor air quality and prevent building damage, there are debates about the actual performance and use of these systems and how deviations observed affect the overall building performance and the well-being and health of the occupants. These debates are increasingly active given the sensitivity of new and renovated buildings on energy use and indoor air quality depending on the field characteristics of ventilation systems.

For this reason the Air Infiltration and Ventilation Centre (AIVC) and the Building and Ductwork Airtightness Platform (TightVent Europe) have taken the initiative to manage a project entitled ‘Improving the quality of residential ventilation systems’.
The objectives of the project were the following:

- collect information on the quality of ventilation systems in residential buildings,
- define causes of quality problems,
- discuss pros and cons of existing approaches to improve the quality of ventilation systems,
- discuss the role of product, system and process innovations to improve the quality of ventilation systems.

The project was launched with a topical session during the 33rd AIVC-Conference in Copenhagen in October 2012 [1, 2]. The session discussed results of large-scale field studies showing striking evidence that installation quality of residential ventilation systems is typically insufficient. Common shortcomings were insufficient supply ventilation capacity compared to design standards, increased noise levels in case of mechanical ventilation systems, and poor operation and maintenance. An overall conclusion was that together with increased building airtightness, more attention should be paid to ventilation system performance and installation quality, in order to guarantee healthy indoor environments.

INTERNATIONAL WORKSHOP

In March 2013 an international workshop was organized in Brussels to discuss the status and perspectives of approaches to secure the quality of residential ventilation systems in various countries. Since field studies have shown evidence that installation quality of residential ventilation systems is typically insufficient, it is important to develop frameworks to improve the situation. In total 13 experts presented the status and perspectives in their country, with a major focus on the voluntary and regulatory schemes developed to secure the quality of ventilation systems in residential construction practice.

The results of the workshop were also presented during a topical session at the AIVC-conference in Athens in September 2013 [3]. During the session a critical review of the pros and cons of existing quality approaches presented at the Brussels workshop were given. Some examples of solutions to tackle the challenges in ventilation system quality were discussed more in detail.

OVERVIEW

This publication collects papers presented at one of the activities organized in the context of the AIVC-project 'improving the quality of residential ventilation systems', primarily at the international workshop.

First an introductory chapter presents a synthesis of experiences and quality approaches related to residential ventilation in various countries. Then the first part of this publication deals with the context and challenges in ventilation systems' quality, such as the observed ventilation system dysfunctions in the field, the development of health-based ventilation standards, and the role of standards and certification schemes to improve and secure the quality of ventilation systems.

The second and main part of this publication contains an overview of the quality assurance approaches in each of the following countries: Belgium, Canada, Estonia, Germany, Finland, France, the Netherlands, Norway, Poland, Romania, Sweden, United Kingdom and United States. Each contribution discusses the development of quality labels and performance display for ventilation products, design and installation guidelines, training and qualification schemes for installers, as well as the implementation of commissioning protocols, maintenance protocols, regular inspections and real performance of residential ventilation systems.

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This publication together with the workshop and conference sessions that have contributed to it, are an initiative by INIVE EEIG (International network for Information on Ventilation and Energy Performance) and its members on behalf of the AIVC (Air Infiltration and Ventilation Centre) and TightVent Europe (Building and Ductwork Airtightness Platform).

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[3] 34th AIVC Conference – Energy conservation technologies for mitigation and adaptation in the built environment: the role of ventilation strategies and smart materials, held in Athens, Greece, 25-26 September 2013, Topical session 'Quality of domestic ventilation systems', Topical session 'Quality of ventilation systems', Conference Proceedings, ISBN 978-2-930471-42-6, p. 288-316.

About INIVE EEIG

INIVE EEIG (**I**nternational **N**etwork for **I**nformation on **V**entilation and **E**nergy Performance) was created in 2001 as a so-called European Economic Interest Grouping. The main reason for founding INIVE was to set up a worldwide acting network of excellence in knowledge gathering and dissemination. At present, INIVE has 11 member organisations (BBRI, CETIAT, CIMNE, CSTB, ERG, ENTPE, IBP, SINTEF, NKUA, TMT US and TNO), and there is interest in joining among other organisations (www.inive.org).

The original reason for creating INIVE was the availability of a strong entity able to act as the Operating Agent for the IEA' Air Infiltration and Ventilation Centre (AIVC). AIVC is the IEA Information Centre that deals with the topic of energy efficient ventilation and air tightness of buildings. Since 2001, INIVE has been the Operating Agent for the AIVC (*www.aivc.org*). As a service provider to the European Commission and the European Agency for Competitiveness and Innovation, INIVE EEIG has been coordinating the European Buildings Platform since 2006 and, since 2009, BUILD UP, which is THE European portal on Energy Efficiency (*www.buildup.eu*). INIVE aims to stimulate and contribute to the creation of new knowledge in key areas of ventilation and energy efficiency. In the ASIEPI project (*www.asiepi.eu*), which finished in March 2010 and was coordinated by INIVE, several critical areas related to energy-efficiency policies were analysed, with a whole range of new findings as a result.

INIVE also wants to facilitate structured collaborations, which go beyond the duration of single projects. The best example of such collaboration is the DYNASTEE-PASLINK network (*www.dynastee.info*), which is the leading network of use and development of system identification techniques and related applications. The DYNASTEE-PASLINK network is a part of the INIVE Activities.

SECURING THE QUALITY OF VENTILATION SYSTEMS IN RESIDENTIAL BUILDINGS: EXISTING APPROACHES IN VARIOUS COUNTRIES

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ABSTRACT

In March 2013 an international workshop was organized in Brussels to discuss existing approaches to secure the quality of residential ventilation systems in various countries. In the past large-scale field studies have shown evidence that installation quality of residential ventilation systems is typically insufficient, so it is important to develop frameworks to improve the situation. In total 13 experts presented the status and perspectives in their country, with a major focus on the voluntary and regulatory schemes developed to secure the quality of ventilation systems in residential construction practice. These schemes intend to influence different steps in the process of the realisation and use of ventilation systems: training, products and systems development, design, installation en commissioning, use, maintenance and inspection.

This article gives a synthesis of the various applied quality approaches, together with practical experience in these countries. A critical review of the pros and cons of existing quality approaches presented at the Brussels workshop is given. Some examples of solutions to tackle the challenges in ventilation system quality will be discussed more in detail.

1 INTRODUCTION

Ventilation of dwellings plays an important role in the recast of European energy performance requirements towards “Nearly Zero Energy Buildings”, because of the need for providing a good air quality in highly insulated and airtight buildings in an energy efficient way. In the meanwhile shortcomings of ventilation systems in operation are frequently reported. Sometimes there is a big gap between the theoretical performance and the performance in actual operation. Typical problems are:

- Insufficient air flow rates
- Poor balancing of air flow rates
- Noise complaints
- Poor quality of supply air
- Inadequate operation by the occupants

Many of these problems are related to a poor design or installation, lack of maintenance, and to a lesser extent, poor product quality. The need for high quality remains an important issue, and could be defined as ‘to meet the end-user expectations’. The occupant requires a comfortable and healthy living area with regard to temperature, light, noise, safety,… and of course also with regard to the air quality. The ventilation system should be easy in daily use and have an acceptable cost. Considering costs, both investment costs and operation costs need an assessment. Operation cost is defined by maintenance costs and energy cost.

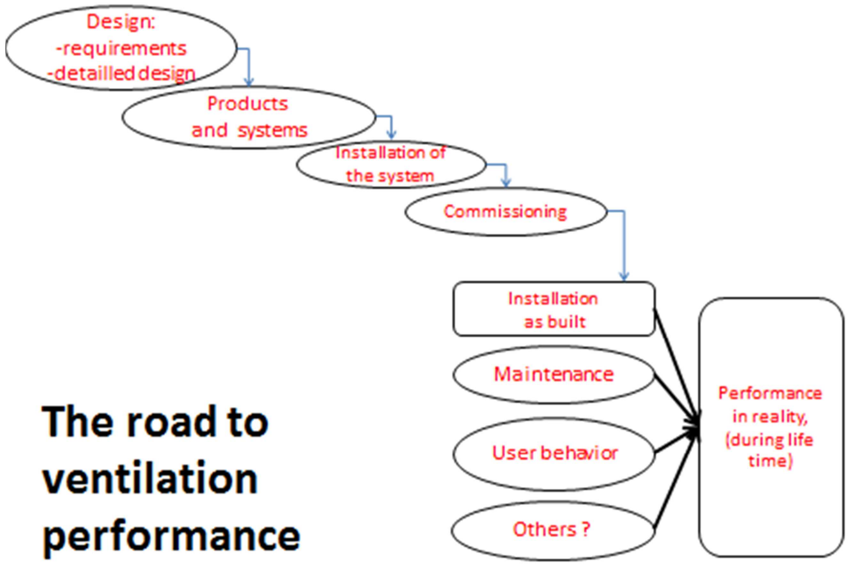

Figure 1: Parameters influencing the final ventilation system performance

At first sight almost every aspect to realize high quality residential ventilation systems is available: ventilation standards, in most countries part of the building code or the EPBD regulation, performance requirements (air flow rates, energy consumption, comfort aspects such as noise levels), product and system standards (and product databases and labels), design and installation guidelines, testing and compliance standards and guidelines, educational and qualification programmes for installers,… However, there is increasing evidence that these instruments, although they are necessary conditions, do not automatically lead to good quality installations (Caillou et al. 2012, Stranger et al. 2012, De Brauwere et al. 2010, AIVC 2013). Reasons for this might be:

- Lack of collaboration and continuity at different stages of design and construction
- Lack of knowledge, awareness and care for quality at different stages
- Savings on investments: lack of willingness to pay for quality
- Lack of training of specific installers and commissioners, no training requirements
- Limited enforcement of legislation

Apart from the aforementioned instruments, there is a need for an integrated quality approach to ensure all available tools are used to achieve quality. These quality approaches may address one or more of the steps that lead to the final ventilation system performance on site. Figure 1 lists some important steps in the design, construction and operation process which influence the final ventilation system performance:

- The consecutive actions in the construction process, all of which affect the as-built situation of the ventilation system: design, selection of products and systems, the installation work and the commissioning.
- User behaviour: use of controllers; selection and use of polluting products like furniture, carpets, …; opening of windows,…
- Maintenance (after inspection if applicable)

In order to collect information on the knowledge regarding the quality of residential ventilation systems in various countries, an international workshop ‘Securing the quality of ventilation systems in residential buildings: status and perspectives’, was organized on March 18-19 in 2013 (AIVC 2013).
This introductory paper reports on the obtained results.

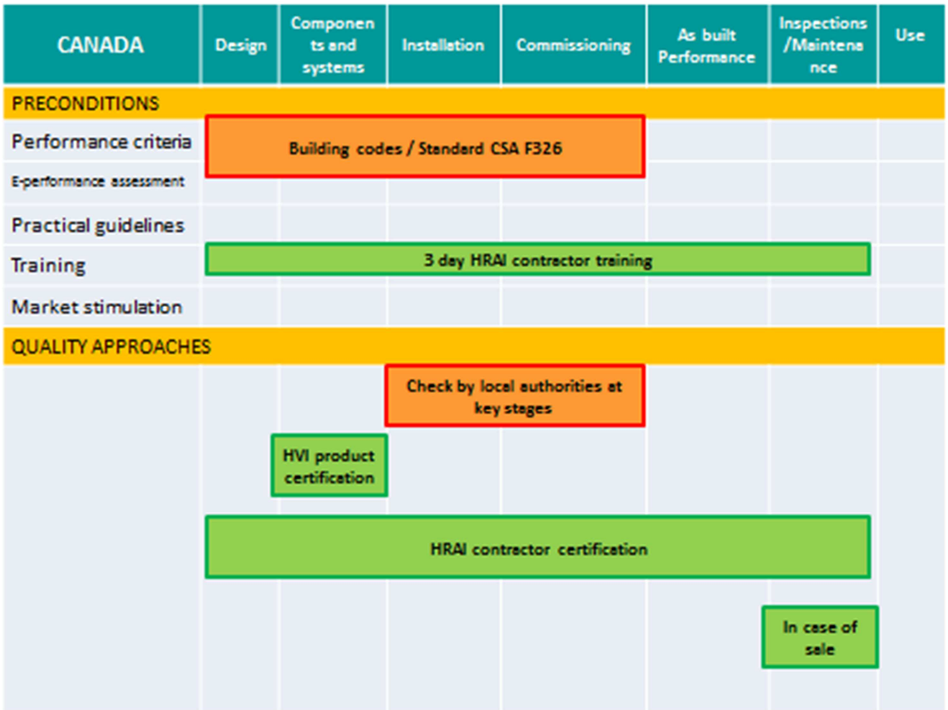

Figure 2: Preconditions and quality approaches in Canada

2 INTERNATIONAL SITUATION

The intention of the aforementioned international workshop was to get an overview of the international situation regarding the following questions:

- What is the knowledge regarding the quality of ventilation systems in residential buildings in various countries?
- What is the status with existing approaches to improve the quality of these systems?
- What can we learn from targeted efforts to characterize or monitor real ventilation system performance?
- How can quality frameworks help to improve the situation and how can they converge with existing regulations or programmes?

Based on the answers, the pros and cons of existing approaches were discussed and ways to improve the situation with key experts from various countries were explored.

Following countries were represented at the workshop with a paper: Belgium, Canada, Germany, Estonia, Finland, France, the Netherlands, Norway, Poland, Romania, United Kingdom, United States, Sweden.

As an example, next paragraphs report some approaches used in 2 countries. The full details of quality approaches in all countries is given in the chapters in the second part of this book.

2.1 Canada (Fig. 2)

In Canada, ventilation is a part of the obligatory building code. A voluntary 3 day contractor training exists that can lead to certification of ventilation installers. Local authorities are deemed to perform a compliance check with the building codes at key construction stages.

Products can get an HVI product certification (Home Ventilating Institute) on a voluntary basis in which rating of product performance in accordance with standards is required. No independent compliance check or permanent follow-up is provided.

On a voluntary basis, contractors can obtain a HRAI contractor certification (Heating, Refrigeration and Air Conditioning Institute of Canada) for 5 years. This requires passing an exam with at least 75 % and signing a certification agreement where the contractor commits to install in accordance with the aforementioned training. No third party compliance check of installations is provided. Withdrawal of the certification however, is possible after complaints. Inspection of installations in use are sometimes performed, in case of homes put for sale.

2.2 Estonia (Fig. 3)

In Estonia, ventilation is a part of the obligatory building code, which refers to EN standards and to Finnish requirements. There is a requirement that installations are maintained once a year, but this is rarely done in practice. Ventilation characteristics are taken into account in the energy performance assessment, which makes the use of Heat Recovery ventilation (HR) almost obligatory in order to meet energy performance requirements. Engineers are educated, there is a ventilation duct fitter qualification, but 75 % of the installers do not apply for it.
A certificate of occupancy is needed before a newly built house is put into use. For detached houses, commissioning can be done by the house owner himself; the authorities lack competence to check for compliance. Product performances are mostly 'self-declared'.

3 OVERVIEW QUALITY APPROACHES

Various quality approaches can be identified. They can be classified as necessary preconditions, as process improvements or as as-built evaluations. A number of interesting quality approaches were identified during the workshop, for each of them we mention some additional conditions to be fulfilled in order to make them work as intended.

3.1 Preconditions

A first precondition is the availability of clear quality criteria for which there is an agreement among the whole sector. As much as possible, these criteria are performance based on the condition they can be evaluated in practice. If these criteria are part of legislation, they should enable enforcement of this legislation. A link between ventilation aspects and the energy performance assessment can be a strong asset. This approach might differ from country to country: from a design approach where planned design choices have an effect on the energy performance, to as-built approaches in which on-site measured performance are a part of the calculation (e.g. air flow rates, fan power).
Example:

- Ventilation requirements are to some extent part of the building code in most countries.

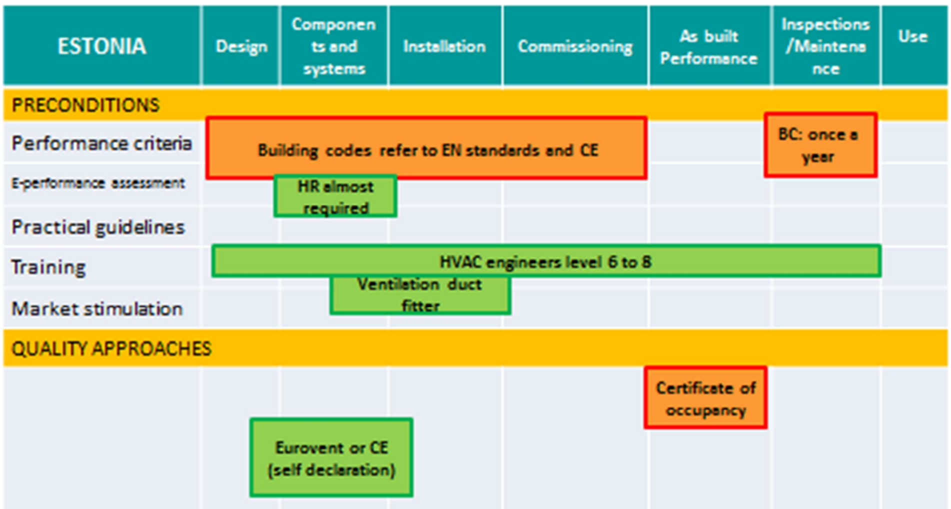

Figure 3: Preconditions and quality approaches in Estonia

In most countries a lot of guidelines on how to design, install and commission ventilation installations is available. An important issue however is whether this information is practical and directly applicable by the contractors.

The professional competences of various persons, active in the process chain, need to be increased. There might be a need for training of different profiles, such as: designers, installers, commissioners, inspectors, maintenance technicians,... The training shouldn't concentrate only on knowledge, but should be directed towards skills and attitudes.
The training approach can be limited to training on its own, or can require theoretical and practical exams and can end up in certification. Competence certification certifies that persons have obtained the required skills in the field of ventilation. The certification should also confirm or proof the ability of the person to conduct a certain function and should therefore be part of a continuing process. Training or competence certification schemes can be voluntary but also compulsory, e.g. when only certified persons are allowed to develop certain professional activities.
Examples:

- HRAI contractor certification (Heating, Refrigeration and Air Conditioning Institute of Canada)
- OVK inspectors (Sweden, OVK = Compulsory Ventilation Inspection)
- License designers and supervisors (Poland)
- Competent persons scheme (UK)

3.2 Process improvements

Before attributing a building permit, the design could be checked, avoiding big mistakes at the start of the construction process. This approach requires that the ventilation system design is already done in a sufficient detailed way at the time of the building permit request, which is normally not the case. The method also requires that the authorities are competent in ventilation matter. Another drawback for this approach is that it gives little guarantee on the as-built result.
Examples:

- Check at building permit (Finland, the Netherlands)
- State Inspectorate (Romania)

With product and system characteristics declaration objective data of various products are available for the designer. This should facilitate a proper selection, best suited to the application. In some cases this classification is limited to some reliable data on energy performance and flow characteristics – in that case the quality aspect is limited to 'quality of data'. Some approaches include additional quality aspects, such as cleanliness, hygiene, acoustical performance and can end up in labelling or certification in which minimum performance levels should be obtained.

With regard to the reliability of the declared performance data, different level approaches can be encountered. In a number of cases data are a result of an initial type testing (ITT), through self-declaration of the manufacturer or performed by a third party laboratory test, on one available sample or through a set of statistically selected samples. As a result, the reliability of the data might differ a lot. A real certification goes beyond an instant snapshot but evaluates the evolution in time through e.g. Factory Process Control (FPC). For some private labels neither the testing procedures, nor the certification process are publicly available, which makes an evaluation of the value of the label difficult. Because most manufacturers also act on an international level, the availability of uniform schemes across EU would be an important asset.

Examples:

- HVI (Home Ventilating Institute) certification (Canada and US)
- EPBD product database (Belgium)
- NF VMC, CSTBat (France)
- TUV-RLT (Germany)
- M1 cleanliness (Finland)
- Product characteristics SAP (Standard Assessment Procedure, UK)
- Eurovent-certification (Europe)

Innovation with regard to products or systems can play an important role in quality improvement. A product can be easy to install or maintain, systems can be self-calibrating, reducing the need of commissioning and the risk of mistakes.

With a follow-up in the installation phase, the authorities may check the compliance with the legal requirements or the building permit. It is crucial to conduct these visits at key stages in the building construction. The impact on the quality aspect is rather low: quality is more than 'legal compliance'. In general authorities lack the competence to go into detail, and often the visits are conducted on a small sample of projects.
Examples:

- Compliance check at key stages (Canada)
- As a part of EPBD compliance (Belgium)

Whole company certification is an integrated approach in which the company is assisted to keep every step of the process under control. Elements are person competence assurance, organisation, management, document and complaint treatment. Such an ISO 9001-like approach seems to be limited to companies of a certain scale.
Examples:

- Qualibat, Qualifelec (France)
- Company registration (Norway)
- Specialist certification (Romania)
- Cleaning companies (Germany)

3.3 As-built evaluation

As-built performance evaluation looks at the final result, without bothering about the process needed to realize it. Evaluation can be limited to compliance with mandatory requirements or can be extended to additional quality issues. The evaluation may include visual, qualitative checks as well as measurements (air flow rates, electric power, acoustics, …). Document availability, e.g. user and maintenance manuals, can be added.
Various concepts may be used as different persons may perform the evaluation:

- Each installation is checked by a third party or by the authorities
- Sample checks of ventilation systems are conducted by contractors. This can also be performed in a framework to certify the ability of installers or their companies to perform these checks.
- Declared by house-owner

Such an approach can be voluntary or mandatory. In some cases it will lead to a 'certificate of occupancy' in which the authorities allow to put the house into use. It requires a systematic organisation with competent evaluators.
Examples:

- Permit to use (Estonia)

- Acceptance before putting into use (Poland)
- VPK (voluntary Ventilation Performance Check, the Netherlands)
- OVK (mandatory Ventilation Inspection, Sweden)

This approach is close to end user expectations, and gives, compared to process approaches, much more liberty when selecting solutions. It gives however direct feedback to the contractor, who might have to improve his process of realisation.

Even an excellent installation at the moment of commissioning, doesn't guarantee a good operation during the total service life. In some countries, regular maintenance is mandatory, but some lack a compliance framework. Inspections after a predetermined time can be helpful in order to define necessary repairs, replacements and maintenance. It could be part of an energy audit, required when putting the dwelling for sale or rent, but detailed ventilation performance isn't always included.
Examples:

- OVK, but not for small dwellings (Sweden)
- Some housing companies (UK)
- As part of energy certification at sale/rent (Belgium, Canada)
- As part of energy audit (Estonia)
- Maintenance of passive stacks by chimney sweeps (Poland)

3.4 Drivers for better quality

An important discussion point for the afore mentioned quality approaches is to make sure the approach enters into action, is correctly used and leads to actual quality improvement for the market as a whole (and isn't limited to a small niche market). This may be achieved by imposing quality approaches with fines in case of non-compliance or by promoting quality approaches using incentives from the authorities.
How far should legislation go to support quality? Legislation can be directed to requirements for design, products, commissioning, inspection or maintenance. Legislation can require minimum skills from ventilation contractors or specialists. Legislation can require an as-built performance evaluation or regular inspections and maintenance. The effect of pure mandatory requirements depends in practice on the country culture. In some countries the existence of a law suffices to have effect, in other countries systematic enforcement is needed. In some countries (e.g. the Netherlands) the authorities avoid enforcing requirements and leave the improvement of the quality of ventilation systems up to market commitments.
Generally speaking, financial incentives can generate an effect. Unfortunately, nowadays the authorities have to reduce this kind of spending.

Good quality ventilation systems can also be valorised in energy performance calculations. Various ventilation characteristics might improve the final performance. When measured performances are not available, (more unfavourable) default values will be used to perform calculations. Examples are the flow characteristics of natural ventilation openings, the effective air flow rate provided by mechanical supply diffusers, type and power of fans, effectiveness of heat exchangers, a proven flow balance. Because of the need to further improve the energy performance of buildings in the next decade, favouring high quality ventilation systems in the EPBD calculation is an indirect way to enhance quality. It is important that this assessment refers as much as possible to the as-built situation, to avoid a merely 'paper quality'.
Example:

- As-built data as a base for E-level calculation (EPBD implementation in Belgium)

Finally, it is important to raise awareness by the users that good ventilation is important for everybody and to get support from the public for the various quality approaches. It is indeed the end-user who will have to pay additional costs!

4 CONCLUSIONS

Although market maturity might differ from country to country, various countries report the same kind of problems regarding residential ventilation systems. Almost every country in this review is looking for approaches to improve quality in the field. To solve the problem as a whole, improvement can be expected from a well selected set of complementary quality approaches. Fully voluntary measures might not work too well, some kind of official enforcement will be required.

5 ACKNOWLEDGEMENTS

The authors wish to thank the Flemish Energy Administration (Vlaams Energieagentschap - VEA) for their financial support to the project VEA/EPB/2012/KDB/1.

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DETAILED ANALYSIS OF REGULATORY COMPLIANCE CONTROLS OF 1287 DWELLINGS VENTILATION SYSTEMS

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ABSTRACT

Originally, Ventilation's historical goal consisted in assuring sufficient air change rates in buildings in order to achieve a good indoor air quality. Within the energy performance era, ventilation must be reconsidered regarding its potential impact on energy consumption. An important challenge for low and very low energy buildings lies in mastering airflows through the building envelope. For these dwellings, it is admitted that this control should be provided thanks to airtight envelopes, associated with efficient ventilation systems, regarding both impacts on energy performance and indoor air quality.
In this framework, the recent French energy performance (EP) regulation (Thermal regulation RT2012) imposes envelope airtightness requirements for any new dwellings. For a single-family dwelling, the requirement is $Q_{4Pa\_Surf} \leq 0{,}6\ m^3.h^{-1}.m^{-2}$, that is around $n_{50} \leq 2{,}3\ h^{-1}$.
This EP-regulation does not include any new requirement on ventilation rates. The dwelling airing is concerned by another 30 years old regulation.
In this context, building's sector wonders about the risk, for a generation of performing airtight dwellings, to lead to an unhealthy indoor air. An important issue consists in increasing our knowledge about the actual efficiency of those ventilation systems, once they are installed and in-use in the buildings.
To this end, we analyzed available data from government building compliance regulatory controls, related to several laws, including energy performance (2005 & 2012) and dwellings airing (1982-1983). Dysfunction analysis observed on a sample of 1287 dwellings allows us to establish an accurate picture of on-site ventilation systems quality. From a global point of view, we observed that 68% of the single-family dwellings, and 44% of the multi-family dwellings; do not comply with the regulation. A finer analysis let us understand more specifically what are the underlying technical and organizational reasons of such results. This original first analysis represents an essential step towards the final goal: find solutions to increase ventilation installation quality.
First, the paper presents the framework of French regulation compliance controls and the content of its precious database. Then, it gives an overview description of the analyzed sample. Finally, results of the detailed analysis of dysfunctions compilation are presented, leading to some proposals for ventilation installation improvement.

KEYWORDS

Ventilation, control, regulation, malfunctioning, site campaign, airflow measurement, dwelling, indoor air quality, regulatory checks, performance

INTRODUCTION

In order to ensure a good indoor air quality, including a satisfactory humidity level in buildings, an adequate air change rate is necessary. On the other side, building energy performance requires a rethinking of ventilation and air change rates, because of their impact on thermal losses : 1) New ventilation systems technologies, such as Demand-Controlled Ventilation (DCV) systems, aim at restricting airflows to the minimum level for healthy buildings. 2) Envelop airtightness treatment becomes essential, especially for low energy dwellings (Erhorn, 2008). Indeed, envelope air leakage entails thermal losses, but also modifies theoretical voluntary airflows circuits in building: airtight rooms may be short-circuited in case of other very leaky rooms. In France, the recent thermal regulation (RT2012) generalizes low energy dwellings and imposes envelope airtightness requirement for any new dwellings. For a single-family dwelling, the requirement is Q_{4Pa_Surf}=0,6 $m^3.h^{-1}.m^{-2}$, that is around n_{50}=2,3 h^{-1}.

This energy performance-regulation does not include any new requirement on ventilation rates. Dwellings airing are concerned by another 30 years old regulation ([5], 1982).

In this context, building's sector wonders about the risk for a generation of performing airtight dwellings to contribute to an unhealthy indoor air. Some questions are emerging in this way : are former regulations ventilation airflows in former regulations sufficient to provide a healthy indoor air in these new airtight dwellings ? For these dwellings, what are the consequences of dysfunctional-working ventilation installations ? What do we know exactly about the actual efficiency of those ventilation systems, once they are installed and in-use in the buildings ?

Some answers are given in recent research projects. The QUAD-BBC project (Boulanger, 2012) confirmed that envelope airtightness drives to a better indoor air quality, thanks to a better mastering of the theoretical airflows circuits in buildings. This project has also confirmed the need for increased airflows during cooking period.

Moreover, a growing number of actors, namely around the Healthvent project (Wargocki, 2012), agree about the idea that ventilation is not a panacea. To achieve a good indoor air quality, contributing to healthy buildings, reduce buildings pollutant sources is a priority.

In order to evaluate the ventilation system efficiency, we analyzed available data from regulation compliance controls, related to several regulations, including energy performance (RT2005 & 2012) and dwelling airing (1982-1983). Dysfunctions analysis of a 1287 dwellings sample allows us to establish an accurate picture of on-site ventilation systems quality. This original first analysis represents an essential step towards the final goal: find solutions to increase ventilation installation quality.

First, the paper presents the framework of French regulation compliance controls and the content of this precious database. Then, it gives an overview of the analyzed sample. Finally, results of the detailed analysis of dysfunctions compilation are presented, leading to some proposals for ventilation installation improvement.

BUILDING REGULATORY COMPLIANCE CHECKS: A PRECIOUS SOURCE OF FIELD DATA

In France, building's owner is legally responsible for the compliance with regulations: when asking for a building permit, he has to sign a commitment to comply with building regulations. Then, he must be able to prove that this building complies with these regulations.

Both during building construction and up to 3 years after commissioning, French authorities have the legal power to proceed to a regulatory compulsory check of his building. Controls are performed by sworn-in and specifically qualified government employees. Their qualification process includes technical and regulatory trainings, and a minimal number of controls performed under a senior employee supervision. The final qualification can be addressed only after 3 years experience.

Several regulations are controlled, including energy performance and airing. The control is based on plans analysis, specifications analysis and calculations, on-site visit, visit at commissioning. Non-compliance with construction regulations is an offence, and controllers' reports are sent to national authorities and to general attorney. Financial penalties may go up to 45k€ (75k€ if repeated). Prison term or banning from practicing may be decided. In general, no penal, no direct financial sanctions are sentenced, but the building's owner must undertake remedial actions to comply with regulation, sometimes very costly. An extensive description of the control process is given in (Lecointre et al, 2009).

The French dwellings airing regulation ([5], 1982) requires on a general and continuous airing system. It describes the compulsory general layouts of ventilation installation. It also sets exhaust airflows in each humid room, depending on the total number of rooms in the dwelling. Total airflows drive to around 0.5 h^{-1} global air change rate in the dwelling. This regulation has been modified in 1983 in order to reduce these airflows in case of demand-controlled ventilation system (DCV), for instance based on humidity. In this case, controls include also additional specific technical guidelines.

This regulatory compliance control includes two sections:

- “What can be seen and operated observation": control of the ventilation system installation, as well as of the whole ventilation equipments set;
- “Exhaust and supply airflows measurements»: check of airflow or pressure difference at air vents (global minimal airflow in dwelling, minimal airflow in kitchen, peak airflow in kitchen, peak airflow in other humid rooms).

The French construction technical regulation observatory (ORTEC) compiles these control data on both sections. In its last report, ORTEC published the following national statistics (CSTB, ORTEC, 2009)[6] :

- 50% of the controlled buildings do not meet the requirements in terms of ventilation mounting, with entails a system dysfunction;
- 43% of the controlled buildings do not comply with the regulatory airflow rates, especially concerning exhaust airflows that are insufficient for 36% of the buildings and excessive in 7%.

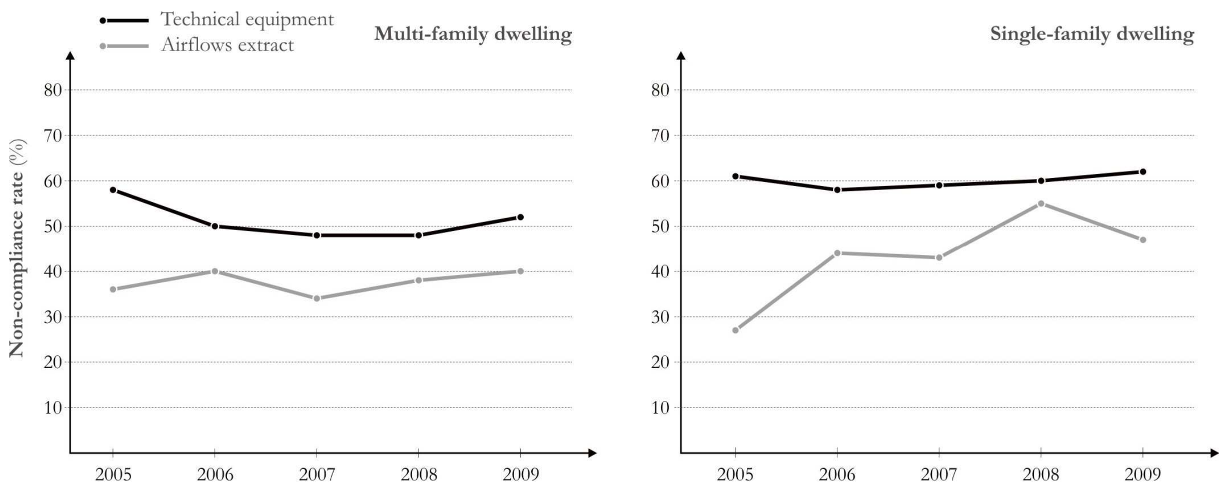

Figure 1: Annual distribution of non-compliance rates, for each type of dwelling, source: ORTEC, CSTB, 2009

However, these national published data are only statistical and mainly analyze “pass-or-fail” tests results. And yet, because comprehensive control reports fully describe all observed non-compliances, even when not related to the regulations, original data are far more detailed and include precise descriptions of the different causes, which affect ventilation performance.
As a result, beyond the regulatory aspect, these detailed reports constitute a potentially important technical database. This paper presents the first results using those data to explain the sources of on-site ventilation dysfunctions.

DESCRIPTION OF THE SAMPLE

We exhaustively analysed 373 control reports performed between 2008 and 2011, by the technical civil servants network of the Ministry in charge of the Construction's sector. These 373 compliance checks reports concerns 1287 dwellings, situated in different climatic zones, and constituted by 88% of multi-family new dwellings (Figure 2).

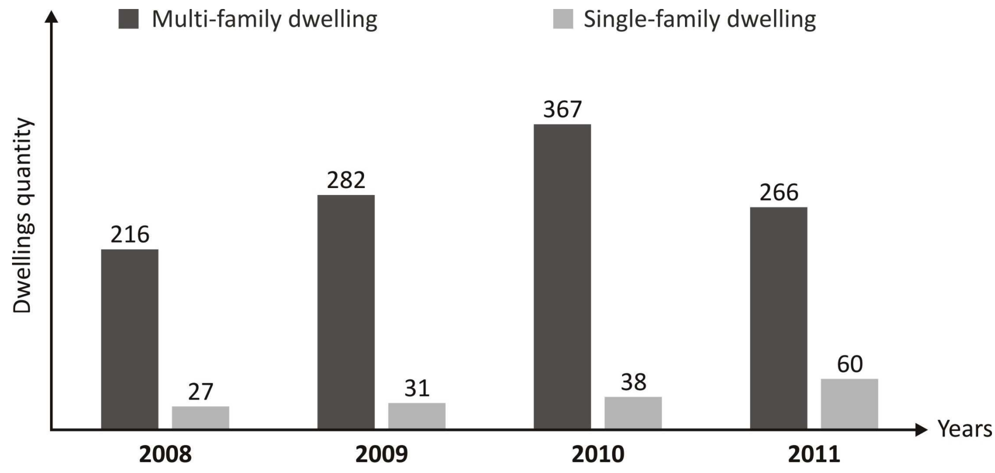

Figure 2: Dwelling type repartition analysed per year

In the sample, nearly all dwellings are equipped with simple exhaust mechanical ventilation. Humidity demand-controlled ventilation accounts for 74% of the sample. Balanced ventilation is found only in 10 single-family dwellings. This repartition (Figure 3) gives a good characterisation of the new dwellings stock in France, since the implementation of the 2005 thermal regulation (RT2005).

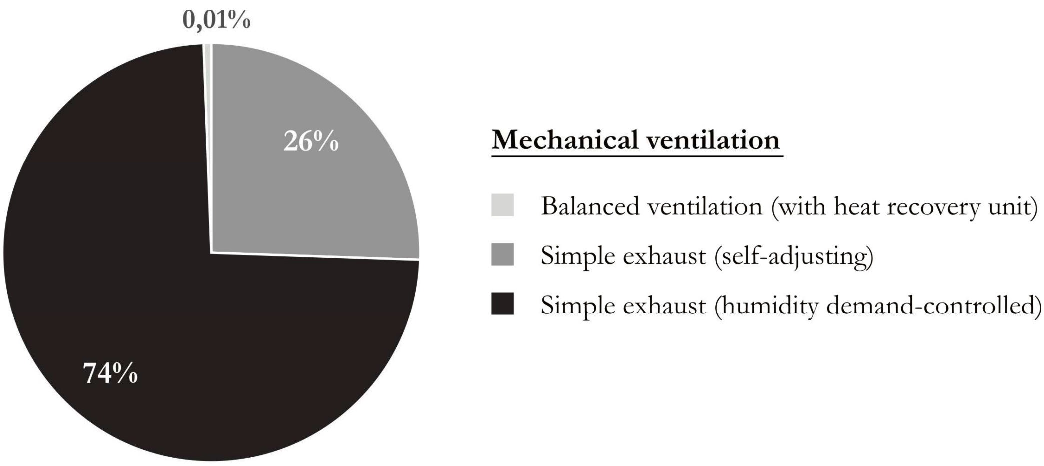

Figure 3: Ventilation system repartition in the analysed sample

The statistical analysis of this sample reveals that 604 dwellings out of 1287, that is 47% of the sample, do not comply with the airing regulation. It also means that 47% of the sample present at least one non-compliance remark. The non-compliance rate is 68% for single-family dwellings, and 44% for multi-family dwellings. These results confirm the national trend (CSTB, ORTEC, 2009)[6].

Among non-complying dwellings, around 1/3 get only one non-compliance point, 1/3 two non-compliance points, and the last third obtain more than 3 non-compliance points.

Dysfunctions type		Amount	(%)
EA	**Air inlets**	**300**	**100**
EA1	Absence of air inlets modules	153	51
EA2	The Implementation of air inlets does not comply with prescribed rules and regulations	54	18
EA3	Presence of inlet air in a humid or service room	36	12
EA4	No mortises in window frames or incorrect size	28	9
EA5	Air inlet excess in the main rooms	17	6
EA6	Obturation of air inlets in one or more rooms	12	4
SA	**Air outlets**	**271**	**100**
SA1	The air outlets does not comply with regulation requirements	102	38
SA2	Control for changing peak flow missing or inaccessible	57	21
SA3	Dysfunction of air outlets equipped with presence detectors	41	15
SA4	Absence of air outlets in one or more rooms	39	14
SA5	Location of air outlets does not comply with regulation and technical requirements	32	12
QE	**Exhaust airflows**	**338**	**100**
QE1	The pressure measures at the air outlets are not correct	196	58
QE2	The exhaust airflows at the air outlets are not correct	142	42
SY	**System configuration**	**124**	**100**
SY1	The system configuration does not comply with the technical note requirements	74	60
SY2	Interversion of air inlet and air outlet	34	27
SY3	The system configuration does not comply with the standardized calculations of thermal regulations	16	13
GX	**Ventilation unit**	**108**	**100**
GX1	The warning signal which indicates ventilation failure is absent	55	51
GX2	The warning signal which indicates ventilation failure is not identified	34	31
GX3	Malfunction or failure of the ventilation unit	14	13
GX4	unsuitable Ventilation unit location and non-compliance with the acoustic requirements	4	4
GX5	Electrical protection group VMC is not independent of other circuit	1	1
CA	**Ductwork and air transfer**	**105**	**100**
CA1	Absence of transfer grids or doors undercut	49	47
CA2	Fouled air discharge in the attic	22	21
CA3	Extracting fouled air ducts are crushed or bent	17	16
CA4	Connecting ducts and duct fittings system are not airtight	17	16
Total of dysfunctions observed		**1246**	**100**

Table 1: Repartition and amount of dysfunctions observed by main mechanical ventilation system elements categories

ANALYSIS OF VENTILATION DYSFUNCTIONS

Based on the analysis of the 373 control reports, the first part of the study consisted in drawing up and classifying all the dysfunctions observed during the controls into a 28 dysfunction points list. These 28 points have then been distributed into 6 representative categories for the main mechanical ventilation system elements: airflow/pressure (DCV) measurement, air inlet, air outlet, system configuration, ventilation fan, ducts (Figure 4).

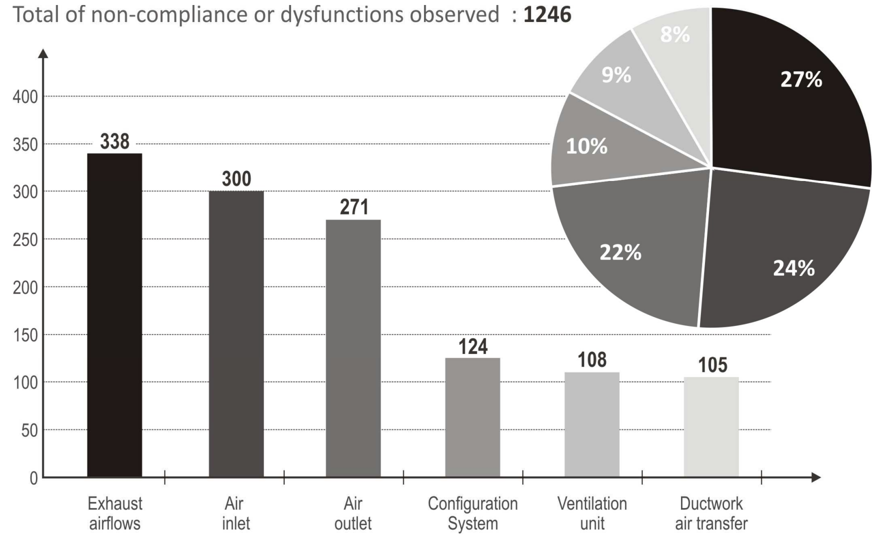

Figure 4: Dysfunctions classifying per category

Statistical analysis shows that the 604 non-complying dwellings account for 1246 non-compliance or dysfunctions points. These points directly or indirectly contribute to a bad ventilation functioning, and also affect indoor air quality.

Figure 4 summarizes statistical results for each category. We can notice that 46% dysfunctions are due to a bad quality of the ventilation mounting terminal devices, that are air inlets (24%) and air outlets (22%). As for air inlets, the most frequently observed dysfunctions are : lack of module, insufficient module quantity, and non-compliance with characteristics of the module (airflows). And yet, on site, terminal devices comply with specific technical terms and conditions and are delivered with plans supplied by the main contractor. The problem lies with the quality of functional layouts mounting, often neglected.
The second important heading (around 1/3) concerns exhaust airflows. Among them, 85% non-compliance cases are due to insufficient minimal airflows, 15% to total excessive exhaust airflows. The frequent causes of these dysfunctions are: implementation of non-complying air outlet, non-adapted airflows regarding the size of the dwelling, bad quality of ventilation ducts mounting (air leakage and pressure losses).

WHY ARE THERE DYSFUNCTIONS? SOME TRACKS OF ANSWERS

In most cases, observed dysfunctions are due to lack of attention at the mounting step.
But they are also due to imperfections during the project managing process and during the decision chain whenever the ventilation installation process is concerned. Indeed, there is a real lack of continuity between program step, design, mounting, and also material and component furniture.
During the execution phase, the lack of ventilation installation quality is due to the actors' dispersion inside multiple technical lots. Thus, in the process of execution phase contracting procedures, ventilation is rarely defined as a specific lot. As a result, the ventilation different components installation is generally divided up among different building trades and no one is/feels responsible for the final result.
We also observed that ventilation installation verification is rare by planned during the construction phase, and that its control at commissioning is not systematic or most incomplete. So, it appears that ventilation commissioning is an absolutely necessary step if one wants to ensure a well working installation upon receipt, with an in-use performance corresponding to the planned one. Recent guides (CETIAT, 2012)[7] describe precisely these receipt procedures.

For further information on quality of ventilation systems in residential buildings, see also French contribution to this workshop (Mouradian, 2013 [10]).

CONCLUSION AND PERSPECTIVES

This analysis confirms that, even if adapted industrial solutions are available, ventilation system dysfunctions are very frequently observed in dwellings, which entail the reliability of these installations. Unfortunately, we found out that, just like in France, other countries (Boersta, 2012; Caillou, 2012)[11][12], also observe that in-site ventilation system mounting is often far from the hoped quality.

This first analysis, based on French regulatory compliance controls and performed only on airing regulation (among 7 other regulations including energy performance), gives clear information about ventilation dysfunctions localisation and qualification. Up to now, only 1287 dwellings have been analysed. In 2013, an important project will harmonize data collection which goal will be to implement a robust database including all other information obtained from building regulation compliance checks.

Besides, these data give few feedbacks on ventilation system installation quality in low or very low energy dwellings (OQAI, 2011)[8], even if some ongoing projects aim at increasing knowledge on this subject. But one thing is sure: even if indoor pollution sources are minimized, the more airtight the dwellings will become, the more essential becomes the need for guaranties on in-site ventilation installation quality. In this way, the French Effinergie+ label plans to reinforce ventilation controls, introducing ventilation airflows and duct leakage measurements at commissioning.[9]

The main stake now consists in determining the ultimate causes for ventilation dysfunctions, and manage major projects to develop tools leading to better practices at every stage of the construction. For instance, many dysfunctions could be avoided through the implementation of quality management tools. With such tools, one could pretty easily, but efficiently, control ventilation system at each stage of the building construction: from design to installation, even including maintenance and final use.

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WHY WE VENTILATE

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ABSTRACT

It is widely accepted that ventilation is critical for providing good indoor air quality (IAQ) in homes. However, the definition of "good" IAQ, and the most effective, energy efficient methods for delivering it are still matters of research and debate. This paper presents the results of work done at the Lawrence Berkeley National Lab to identify the air pollutants that drive the need for ventilation as part of a larger effort to develop a health-based ventilation standard. First, we present results of a hazard analysis that identified the pollutants that most commonly reach concentrations in homes that exceed health-based standards or guidelines for chronic or acute exposures. Second, we present results of an impact assessment that identified the air pollutants that cause the most harm to the U.S. population from chronic inhalation in residences. Lastly, we describe the implications of our findings for developing effective ventilation standards.

KEYWORDS

Indoor air quality; hazard analysis; residential; DALYs; ventilation

INTRODUCTION

The primary purposes of ventilation in buildings are to provide a sufficient oxygen supply for the occupants and to remove any hazardous substances or noxious odors in the indoor air. For thousands of years societies have realized the need to set or adjust ventilation for specific indoor tasks. The initial inception of residential ventilation is unknown, but likely was from neolithic times and used to remove combustion gases from indoor heating and cooking such as introducing vents for fires. According to Kuhnl-Kinel [1], ancient Egyptians noticed that stone cutters working outdoors had fewer respiratory problems, people in the Middle Ages realized that air in building could transmit disease, and in 1600 the king of England required buildings to be a certain height with tall, slim windows to facilitate the removal of smoke from heating and cooking.

Traditionally in residences the dominant form of ventilation has been natural ventilation including infiltration. In older, leakier homes infiltration from weather driven flows through cracks in the building's exterior may provide sufficient ventilation for residents. In the 1960s and 1970s home construction shifted from natural materials to new synthetic materials and new construction products; and there was increasing interest in tightening homes to conserve energy due to the energy crisis of the 1970s. The increased tightness in homes reduced ventilation that, along with synthetic materials, led to dramatic increases in residential mold related problems and potential issues with combustion spillage. There was also increasing concern about the impact of material emissions on the health of occupants as new materials were introduced.

People spend the majority of their time in residences [2], making indoor air quality an increasing concern. It has been widely recognized that the health burden of indoor air is significant [3-4]. Current ventilation standards are ostensibly set to protect the health of residents. The American Society of Heating, Refrigerating and Air Conditioning Engineer's (ASHRAE's) Standard 62.2 is the most widely accepted residential ventilation standard in the United States. ASHRAE developed Standard 62.2 "Ventilation and Acceptable Indoor Air Quality in Low-Rise Residential Buildings" to address indoor air quality (IAQ) issues (ASHRAE 2010). ASHRAE 62.2 is now required in some building codes, such as California's Title 24, and is treated as a standard of practice in many energy efficiency programs and by organizations that train and certify home performance contractors. The standard specifies an overall, residence-level outdoor air ventilation rate as a function of floor area (a surrogate for material emissions) and the number of bedrooms (a surrogate for occupant-related emissions) and requires bathroom and cooking exhaust fans. The focus of the standard generally is considered to be the overall ventilation rate. This emphasis has been based on the idea that risks indoors are driven by continuously emitted, distributed sources such as formaldehyde from furnishings and bio-effluents (including odors) from humans. The required level of whole residence mechanical ventilation was based on the best judgment of experts in the field, but was not based on any analysis of chemical pollutant concentrations or other health-specific concerns.

While whole residence ventilation has been recognized as an effective method for reducing many indoor risks, there are significant costs associated with high ventilation rates due to moving and conditioning the air. Certain human needs likely set the minimum for ventilation, based on the requirements for providing sufficient oxygen and removing CO_2. However, energy demands and associated greenhouse gas emissions can be reduced by using source control and efficient task ventilation to remove other contaminants of concern. To effectively design residential ventilation systems to maximize health while minimizing ventilation costs, we first need to specify our objectives for ventilation.

This paper presents a summary of the ongoing work at the Lawrence Berkeley National Laboratory to develop a health-based ventilation standard. This work focuses on non-biological indoor air pollutants. Ventilation affects moisture in the indoor environment, and moisture affects mold development. However, ventilation is not an effective method of controlling whole residence moisture loads (although it is effective in bathrooms) because many locations have higher outdoor than indoor humidity. First we discuss a hazard assessment of indoor pollutants that identified the air pollutants in residences that exceed health-based standards and guidelines. Second, we present the results of a study that determined the relative importance of different pollutants to health. Lastly, we discuss the impact of these results on ventilation standards.

HAZARD ASSEMENT OF INDOOR POLLUTANTS

The initial step in this broad effort was to conduct a hazard assessment of non-biological air pollutants – e.g. including chemical gases and particles – in residences [5]. The analysis compiled data from published studies reporting measurements of air pollutants in residences. That literature review identified 86 articles that were relevant to acute and chronic exposure in residences and considered a broad collection of contaminants measured indoors regardless of pollutant source. The contaminants included some emitted purely from indoor sources, some that enter predominantly from outdoors, and some having both indoor and outdoor sources.

Summary results were compiled and used to calculate representative mid-range and upper-bound concentrations relevant to chronic exposures for over 300 pollutants and peak concentrations relevant to acute exposures for a few pollutants. For over 100 pollutants, measured concentrations were compared to available chronic and acute health-hazard standards and guidelines from the U.S. Environmental Protection Agency (USEPA), California Office of Environmental Health Hazard Assessment (OEHHA), the U.S. Occupational Safety and Health Administration (OSHA), the Agency for Toxic Substances and Disease Registry (ATSDR), and the World Health Organization. Fifteen diverse pollutants were identified as potential chronic or acute health hazards for many homes. A subset of pollutants were identified as priority chemical pollutants based on the prevalence of the pollutant in homes and the quality of available measurements in homes. Table 1 lists the identified priority hazards.

Priority Pollutants for Chronic Exposure	**Potential Acute Exposure Concerns**
Acetaldehyde	Acrolein
Acrolein	Chloroform
Benzene	Carbon Monoxide
Butadiene, 1,3-	Formaldehyde
Dichlorobenzene,1,4-	NO_2
Formaldehyde	
Naphthalene	
NO_2	
$PM_{2.5}$	

Table 1. Pollutants that potentially pose an adverse indoor health risks.

The hazard assessment narrowed the list of hundreds of chemicals to a much smaller group of pollutants of concern. But this approach considered only disease incidence for cancer standards and disease potential for non-cancer standards; it did not consider disease severity. Prioritizing mitigation efforts among residential indoor air pollutants, and comparing their cumulative health damage to other environmental hazards requires a consistent and comparative metric that accounts for both disease incidence and the severity or costs of the health endpoints. This need motivated development of an impact assessment methodology for indoor air pollutant inhalation.

HEALTH DAMAGE OF CHRONIC INDOOR AIR EXPOSURE

We synthesized disease incidence and health damage models to develop a methodology for quantifying indoor air quality and then applied the methodology to calculate the population average health damage due to chronic inhalation of non-biological air pollutants in U.S. residences [6]. We first analyzed published data to calculate mean exposure concentrations and then estimated age-dependent inhalation air intake over the course of a year. We used disease incidence and disease damage models to predict the pollutant-specific and total health damage in Disability Adjusted Life Years and to identify the pollutants that dominate impacts on human health.

Determining Annual Population Health Damage

To determine the annual population health damage we compared estimates of current air pollutant intake in U.S. homes (using measurement based estimates of population-averaged, residential chronic exposure concentrations) to the theoretical case of a home with no indoor pollutant sources and no pollutants infiltrating from outdoors, i.e. with homes having no pollutants in the indoor air. Population intake via other micro-environments was held constant as a baseline for which inhalation in residences adds an increment of harm.

The Disability Adjusted Life Year (DALY) metric is a powerful tool for quantifying and inter-comparing the damages from health endpoints that can result from specific pollutant intake [7]. DALYs quantify overall disease damage including both mortality and morbidity. DALYs are the equivalent years of life lost to illness or disease and include years lost to premature death (YLL) and equivalent life years lost to reduced health or disability (YLD).

$$DALY = YLL + YLD \quad (1)$$

The years of reduced health are weighted from 0 to 1, based on the severity of disease, to calculate equivalent years lost. For example, a 5 year illness that reduces quality of life to 4/5 that of a healthy year is valued at 1 DALY lost.

Several authors have determined the DALYs lost per incidence of specific diseases using the preeminent work of Murray and Lopez [7-11]. Multiplying a disease incidence rate by a "damage factor" yields a rate of lost DALYs per disease incidence.

$$DALYs = \frac{\partial Damage}{\partial Disease\ incidence} \cdot Disease\ Incidence \quad (2)$$

Damage rates multiplied by available disease incidence statistics , integrated over all diseases of interest, are often used to determine the total burden of disease in a community. This method was used by the World Health Organization to determine the disease damage for 192 countries [11].

Our analysis used the compilation of measured concentration data to calculate total DALYs lost due to inhalation of air pollutants in residences. We approached this using three different methods. The first method was for criteria pollutants, which are more extensively studied and have a larger body of available epidemiological studies. We aggregated the available Concentration-Response (C-R) functions in the literature to determine disease incidence as a function of a change in airborne concentrations. For each health outcome for each criteria pollutant we multiplied the change in disease occurrence rate by the damage factor for that disease. This level of epidemiological data was not available for the majority of remaining pollutants. The second method that we used was primarily for air toxics or hazardous air pollutants which have limited epidemiological data, but extensive data from toxicological studies. This method used the work of Huijbregts et al. [7] to calculate the health damage associated with the intake of non-criteria pollutants. Huijbregts et al. [7] determined cancer and non-cancer mass intake-based damage factors by synthesizing disease damage factors and animal toxicology based disease incidence rates. This method is much more uncertain than using C-R functions which is reflected by significantly larger uncertainties. The third method was used for pollutants that had already had been significantly studied and had available literature studies apportioning specific disease rates to exposure. This applied to radon and secondhand tobacco smoke (SHS). The population average DALYs lost due to radon, acute carbon monoxide (CO) and SHS were determined based on estimates of disease incidence by multiplying them by the damage factors for those diseases.

Figure 1 shows the damage in DALYs per year per 100,000 people from exposure to the 15 pollutants with the highest central estimate of damage. The whiskers indicate the aggregate uncertainty (95th percentile confidence interval) in the disease incidence and disease damage factors. Figure 1 shows the clear result of our analysis: on a population average, the most harmful pollutants in residential indoor air are $PM_{2.5}$, SHS, formaldehyde, acrolein, radon and ozone. The hazards of SHS and radon are more widely recognized and focused in a smaller fraction of homes. By contrast, $PM_{2.5}$, acrolein, and formaldehyde are present at substantial levels in most homes yet there may be less widespread recognition of these hazards. Formaldehyde is primarily emitted from materials throughout the home. Acrolein is primarily emitted from materials and cooking [12]. $PM_{2.5}$ concentrations indoors, unlike acrolein and formaldehyde, are due to both indoor and outdoor sources and outdoor concentrations may exceed indoors in many locations [4].

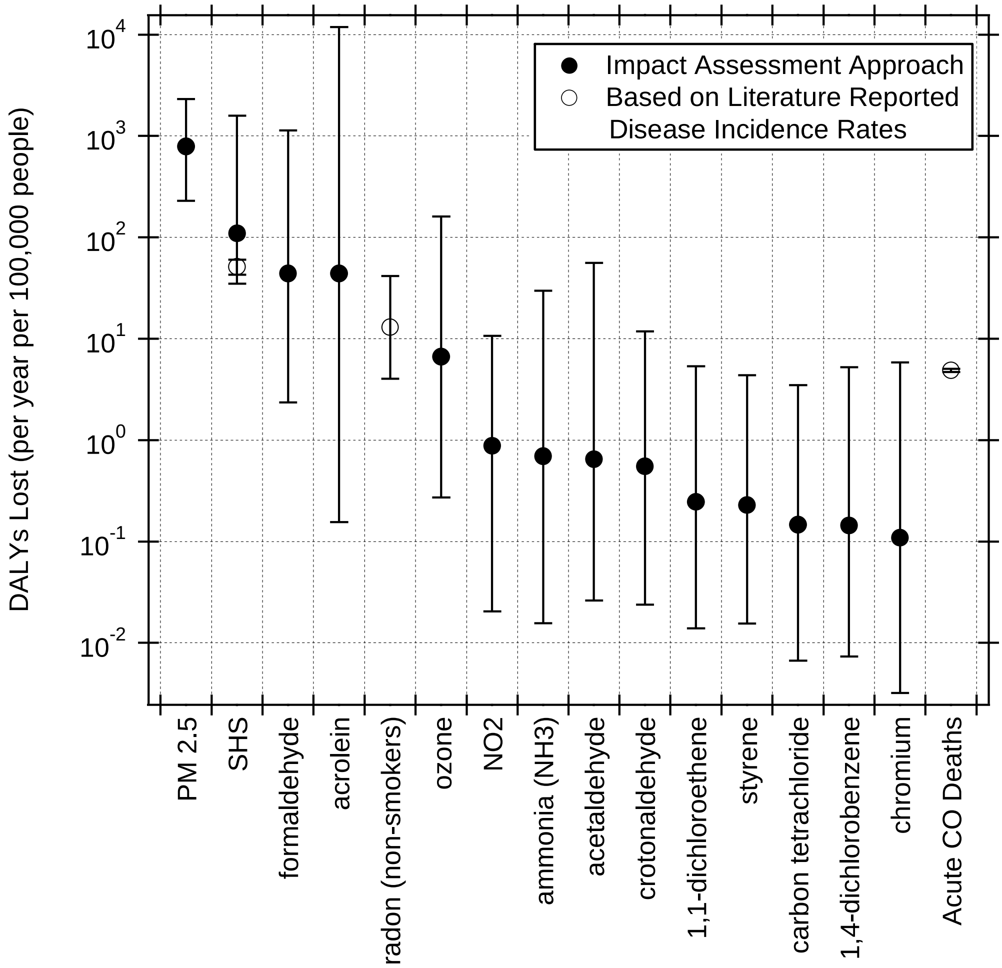

Figure 1. Estimated population averaged annual cost, in DALYs, of chronic air pollutant inhalation in U.S. residences; results for the 15 pollutants with highest mean damage estimates.

To explore possible variations in the health impact rankings of pollutants across homes, we used a Monte Carlo approach to calculate the total chronic health damage from exposure to all pollutants included in our analysis, except radon and SHS. For each model run, we sampled with replacement from the distribution of estimated damage for each pollutant and calculated an estimate of total health damage for the home. We assumed independent variability of all pollutants. This was repeated for a sufficient number of homes to yield a stable mean and standard deviation for the total health damage. We assumed that individual pollutant damages vary independently. This approach did not explicity account for any synergistic or antagonistic interactions of pollutant health effects. The resulting distribution of total health damage and the characteristics of each set of individual pollutant contributions to the total health damages were analyzed. For 80% of the sample sets (calculated damages for individual homes), $PM_{2.5}$ was the largest contributor. For 16% of the sample sets acrolein was the dominant contributor and for 4% of the sample sets it was formaldehyde. The dominant contributor was a compound other than these three in less than 0.25% of the sample sets. For 90% of the sample sets, acrolein, formaldehyde, and $PM_{2.5}$ contributed more than 80% of the total health damage. This reinforces the finding that these three pollutants account for the majority of chronic health from intake of air pollutants in non-smoking homes. We estimate that the current indoor air quality related heath damage to the U.S. population from all sources, excluding SHS and radon, is in the range of 4-11 mili-DALY/p/yr (mili-DALYs per person per year). This indicates that the damage attributable to indoor air is, comparatively, somewhere between the health effects of road traffic accidents (4 mili-DALY/p/yr) and all-cause heart disease (11 mili-DALY/p/yr) in the U.S. The compounds that dominate that total are $PM_{2.5}$, acrolein, and formaldehyde.

IMPLICATIONS FOR VENTILATION STANDARDS

Ventilation standards have the potential to significantly improve indoor air quality (IAQ) in the vast majority of homes. Identifying the pollutants that drive the risks will allow us to make suggestions for modifying the current ventilation standards and identify areas where further research is needed. This section describes how two particular elements of ventilation standards can improve IAQ: overall air exchange rate and localized exhaust ventilation.

Current ventilation standards focus primarily on providing the right amount of overall ventilation for a home based on the idea that the main drivers for pollutant concentrations are furnishings and occupants themselves. A reasonable lower bound for the overall ventilation rate would likely be the airflow needed to control for body odor [13]. Additional air flow is needed to control concentrations of pollutants that have diffuse emission sources in residences. Our analysis indicated that material emissions of acrolein and formaldehyde are the main pollutants that need to be controlled with an overall ventilation rate and the rate should be set at levels that would provide safe indoor concentrations of these pollutants.

There is insufficient material emission data currently to set a ventilation rate based on acrolein, however an appropriate ventilation rate for formaldehyde has been suggested based on California health standards of 0.3 air changes per hour for existing homes and 0.5 for new homes [14]. There are two main concerns with providing ventilation at these levels: 1) the cost of conditioning the extra airflow and 2) bringing in outdoor pollutants.

One way of reducing the needed overall ventilation for a home, and the associated energy and cost penalty, would be source control. Currently in the U.S. there is not sufficient information to estimate the benefits of source reduction by simulating the replacement of specific materials or applying specific existing standards or guidelines for material emissions [15]. Developing these databases could aid in the reduction of material loading of formaldehyde and acrolein. Implementing standards that reduced material loading in homes would reduce the required ventilation rate and save energy.

Increasing air flow through the home can increase the rate at which outdoor pollutants are brought indoors. Our study identified $PM_{2.5}$ as the most important pollutant for health in residential environments. While indoor sources such as combustion and chemistry significantly impact indoor $PM_{2.5}$ concentrations, a significant fraction of homes may have higher concentrations outdoors than indoors indicating that more ventilation may actually increase health risks [4]. Providing ventilation air via filtered supply or filtered balanced ventilation using heat/enthalpy recovery ventilators is one potential solution. Another option is to filter the indoor air independent of the ventilation system to reduce indoor $PM_{2.5}$ concentrations. Including measures to reduce indoor particle concentrations in ventilation standards could greatly improve IAQ from a health perspective.

Our analysis indicates that removing pollutants near their point of release using effective localized exhaust ventilation is key to maintaining good IAQ. The two main types of localized exhaust in ventilation standards are kitchen and bath ventilation. Effective kitchen ventilation is needed to mitigate acute pollutant events resulting from combustion based cooking appliances and food preparation activities. Task ventilation can also significantly mitigate chronic exposures by removing pollutants at their source. ASHRAE 62.2 requires a kitchen exhaust fan that is above the cooktop and provides at least 100 cubic feet per minute (roughly 50 $m^3 h^{-1}$) of airflow while producing 3 sones or less of noise. The standard doesn't specify a minimum pollutant capture efficiency or sound limits at higher flow rates. Requiring a high pollutant capture efficiency and potentially requiring automatic fan use when the range is operated could significantly improve indoor air quality. Four out of five of the identified acute contaminats of concern (except chloroform) are emitted by combustion or cooking. It is critically important to make sure that there is effective ventilation for all indoor combustion. Research is needed to determine if the health benefit of adding a commissioning requirement to ventilation standards is worth the cost.

Effective bath fans are also critical for providing good indoor IAQ. Bath fans remove bio-effluence, moisture and pollutants generated in bathroom activities such as personal care product use and showering. Showering has been shown to elevate concentration of chloroform above acute thresholds[16]. Bathroom exhaust flow rate requirements should be designed to keep chloroform levels below acute thresholds. Further research is needed to determine which episodic activities in bathrooms may lead to acute exposures.

CONCLUSION

The main air pollutants of concern for regulators setting residential ventilation standards are formaldehyde, acrolein, and $PM_{2.5}$. This implies that whole-residence ventilation rates should be based on controlling formaldehyde and acrolein. Filtration of incoming or house air to remove $PM_{2.5}$ would substantially improve indoor air quality.

Effective task ventilation is critical for controlling acute exposures in residences. All combustion in homes should be effectively vented and cooking exhaust systems should be required to meet minimum pollutant capture efficiency standards.

The identification of formaldehyde, acrolein and $PM_{2.5}$ as the highest priority pollutants for chronic exposure opens opportunities to improve energy efficiency through consideration of control measures complementary to ventilation.

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TECHNICAL GUIDELINES FOR VENTILATION SYSTEMS (HEALTHVENT PROJECT)

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ABSTRACT
The paper presents the descriptive component of guidelines for health-based ventilation dealing with operation and maintenance of ventilation systems. The guidelines were developed as part of European HealthVent project objectives. This part of Health Vent project results is based on the data of the most common problems related to the current ventilation practice and the methods of their mitigation. To identify the ventilation-related problems in practice and cover the existing requirements in national regulations, the literature survey was carried out and a questionnaire was sent to HealthVent project partners and REHVA network of experts in 17 EU countries. The results show that there is a strong need for descriptive guidelines prescribing technical features of well performing ventilation that would reduce the risk of problems occurring when operating a HVAC system. A list of such guidelines was developed. It covers 21 elements that have an impact on the performance of ventilation. Guidelines were grouped in three categories dealing with: (A) reducing exposure to pollutants associated with ventilation systems; (B) avoiding specific sources of pollution related to ventilation system; and (C) Compliance of regulations operation, and maintenance. This presentation is based on the paper presented in Healthy Buildings 2012 Conference [1] and the results of the Work package 5 reports of the project [2]. The focus of HealthVent project was on residential buildings, schools, kindergartens and offices.

KEYWORDS
ventilation systems, ventilation design, ventilation guideline

INTRODUCTION
The paper describes results of a workgroup of the currently running HealthVent project, supported by the European Commission – Directorate General for Health and Consumers, aiming at developing health-based ventilation guidelines for Europe. The project identified six complementary approaches that shall be considered when developing the final guidelines for health-based ventilation. They are as follows:

1. Approach in which guidelines are based on the emissions from humans – activity based ventilation. Markers: CO_2 and humidity.
2. Approach in which guidelines are based on the results from epidemiological studies showing the relationship between ventilation and health in non-industrial indoor environments.
3. Approach in which guidelines take into account outdoor air pollutants – i.e. PM, including pollen, and ozone.
4. Approach in which guidelines are based on the toxicological data on pollutants such WHO guidelines, labelling systems, etc.
5. Approach in which guidelines are based on the existing field and laboratory data showing the relationship between concentrations (emissions) of pollutants and ventilation.
6. Approach in which guidelines are based on ventilation related problems detected in practice.

Approaches 1 to 5 will lead to creation of the guidelines prescribing ventilation rates (quantitative guideline) while the approach 6 will contribute to developing descriptive guideline prescribing technical means and solutions to avoid and mitigate the problems related with ventilation system. The contents of the last proposed approach (6.) are described in this paper.

Ventilation systems in Europe

One of the tasks of the HealtVent project was also to carry out a survey of existing ventilation systems throughout Europe, with the aim of providing a broader picture of the type of ventilation systems used. The data was collected from project partners and other national experts on ventilation by means of a specific questionnaire. Each defined ventilation system was analysed over several time periods for five building groups: houses, apartments, schools, kindergartens, and office buildings. The responses were based either on national studies or national statistics and experts' own data. Data was submitted by 11 European countries. A summary of the results is available in the REHVA Journal [3].

The analysis of the ventilation systems in the total building stock showed that most of the buildings are still naturally ventilated. However, the degree of natural ventilation varies, and is the highest in the southern European countries. It can also be noted that the share of naturally ventilated buildings is highest among houses and apartments, and lower among offices, schools and kindergartens. Data collected for Bulgaria, Finland, France, Germany, Greece and Italy for the current building stock shows that in dwellings, natural ventilation systems are still dominating, ranging between 65% and 100%, except in Finland where the share of natural ventilation systems is only 28%.

The evolution of the types of ventilation systems installed in buildings, in certain periods shows that the number of mechanically ventilated systems is gradually increasing. A sharp increase of mechanical ventilation systems can be seen in certain countries after the building regulations have become more stringent, and cannot be fulfilled by natural or hybrid ventilation systems. Also within mechanical ventilation systems there has been a gradual shift from mechanical extract or supply ventilation to balanced mechanical supply and extract ventilation (with or without heat recovery) in almost all types of buildings.

From the data, it is clear that the highest proportion of mechanical ventilation systems is in the Northern European countries where the climate is cold, and much lower in countries of the southern Europe. However, in countries with continental climate and relatively cold winters such as Romania, the share of mechanical ventilation systems is also low, which might suggest that the economic situation of a country also has an effect on the ventilation systems.

The survey clearly shows that there is large difference in the numbers of ventilation systems among European countries, even though the ventilation and building regulations have been recently updated. Moreover, natural ventilation systems are still widely used in some countries and in some building types where the regulations require mechanical ventilation. This suggests that the regulations are not being followed in practice and compliance with regulations is poor.

METHODS

In order to develop the descriptive guidelines, various peer-reviewed publications, European standards, and material gathered with specially developed questionnaires for this purpose distributed to the REHVA network of experts on ventilation was reviewed. The information was collected which was related to technical features of ventilation systems and their effect on human health in indoor nonindustrial environments. This information was checked against the list of technical features of ventilation systems being possible source of the negative health effects; this list was identified by the EUROVEN group [4]. The results of the questionnaires showed that many of the technical properties of ventilation systems are not dealt within the national regulations. This indicated that there is a strong need for a descriptive document unfolding technical features of well performing ventilation. Such a document could be used to improve the performance of ventilation and prevent the problems occurring in ventilation systems, as well as it could provide supplements that need to be included in the national regulations and future European ventilation standards.

The draft of the descriptive guidelines was developed during a brainstorming session of the project group. The participants discussed the hypotheses on the role of ventilation and HVAC systems for human health developed by EUROVEN [4]. The list of measures was proposed showing how to deal with the problems related to ventilation was developed and further edited by REHVA.

After the draft of descriptive guidelines were developed, as outlined above, the existing European Standards on ventilation were searched for whether they include the same recommendations. The results showed actually that many of recommendations included in the draft of descriptive guidelines are already part of many standards. It should be noted, however, that standards are not binding documents if not referred in the national or EU regulations, which may result that they may not be used in practice. Additional review of the national building regulations and codes was therefore performed and it showed that only some of the recommendations included in the draft of descriptive guidelines are included in the national building codes. This may suggest that are basically not used in practice.

RESULTS

The contents of the proposed descriptive guidelines were developed according to the approach based on the performance of ventilation systems in existing buildings and the potential problems of indoor air quality directly related to the ventilation systems in existing buildings. The proposed guidelines are created along three groups:

- Group A showing measures leading to avoidance of specific sources of pollution related to ventilation system
- Group B showing measures leading to reduction of exposure to pollutants with ventilation
- Group C showing measures leading to proper operation and maintenance, and compliance with regulations, of ventilation systems

Group A – Actions to avoid specific sources of pollution related to ventilation system

A1 Avoid uncontrolled condensation in HVAC components. Uncontrolled condensation and moisture in components of a HVAC system can cause microbial growth. Condensation should be only of controlled type. Outdoor air intakes should be designed to manage rain entrainment, rain intrusion and snow entrainment.

A2 Impose limits of noise generation by the ventilation system. Limits for acceptable noise levels shall be provided for different types of occupied spaces (e.g. living rooms, sleeping rooms, classrooms, kindergarten playrooms, offices etc.).

A3 Avoid air cleaning that produces ozone in the system. Air cleaners that generate excess ozone during the air cleaning process should be avoided. Ozone can be transferred to rooms via ducts or directly if local air cleaners are used. Ozone reacts with other indoor pollutants and may generate toxic chemicals that may pose health threat for occupants.

A4 Control the quality of materials used in ventilating systems. Ventilation systems should be constructed of non-low-polluting materials, so that ventilating system itself does not become a source of pollution. Materials used for construction of ventilation system should be tested and certified for emissions and acceptable quality.

A5 Enforce minimum distances between outdoor pollution sources and fresh air intakes The distance between outdoor pollution sources (e.g. chimney, sanitary vents, exhaust air openings, and cooling towers) and outdoor air intakes, including those in natural ventilation systems, should be sufficient to secure no ingression of pollutants into the ventilation air.

A6 Capture and remove pollutants at source. To reduce ventilation rates and protect occupant from exposure to pollutants it would be necessary to capture and remove pollution at source. If not caught at source, pollutants may spread across the room. Instead of local air extraction at source with lower ventilation rates, all room ventilation with dilution and higher ventilation rates is needed (e.g. use of home kitchen range hoods instead of general kitchen ventilation).

A7 Avoid adiabatic humidification and cooling. Adiabatic humidification and cooling (when water is sprayed directly to supply air) may create conditions in humidifiers that are favourable for microbial growth. If such humidifiers are not regularly cleaned, they can become a source of contamination of ventilation air and may create health hazards.

A8 Regulate leakage of exhaust or extract air duct systems. Air tightness of ductwork should be regulated to avoid pollutants from exhaust ducts in overpressure to enter cleaner rooms through duct leakage. E.g., polluted exhaust air ducts in overpressure (e.g. fans is installed locally in the room) from toilettes, kitchens, etc. running through cleaner rooms such as offices, classrooms etc.

Group B – Actions to reduce exposure to pollutants with ventilation

B9 Determine ventilation rates to reduce concentrations of pollutants originating from building materials and occupants activities to acceptable levels. Materials used in buildings and activities of occupants emit pollutants. Ventilation should be connected to exposures occurring indoors and reduce these exposures to the acceptable levels.

B10 Provide always ventilation to meet IAQ requirements. Materials in buildings and occupants with their activities emit pollutants. Therefore there should always be ventilation in buildings (natural or mechanical) so that the IAQ requirements are met. In case of the failure of a mechanical ventilation system, the provisions should be made that the building is ventilated e.g. by allowing the windows to be opened.

B11 Filter outdoor air for ventilation. Removal efficiency and stages of filters should be adequate to air quality. Particulate matter in outdoor air includes particles from combustion, traffic, industry and nature like pollen and spores. They should be removed from the air used for ventilation. This applies also for case when air is circulated from return air.

B12 Avoid leakage of soil air into living spaces in order to prevent enhanced radon concentrations. Foundations should be designed so that soil air leakages are prevented. All piping, penetrations and openings in foundation are potential entry routes. Pressure differences due to unbalanced ventilation increase leakage of soil air into living spaces. This may increase indoor radon concentration and soil-borne odours. In extremely airtight buildings the potential for pressure differences is higher than in less airtight buildings.

B13 Control air distribution in building and rooms. Air flows in the building should be balanced so that the primary flow of air is from rooms (areas) with higher IAQ to rooms with potentially lower IAQ and higher pollutant generation (e.g. from living rooms to bathrooms or kitchens). Good air distribution in rooms may reduce the exposure to pollutants by improving the effectiveness of ventilation (pollutant removal and ventilation efficiency).

Group C – Actions to achieve the compliance of regulations regarding operation and maintenance

C14 Enforce commissioning of the system (conformity of design and installation). Commissioning should be enforced to check that ventilation system after completion corresponds to the use of the building and the design of the system. Commissioning process is described in several documents and it should include balancing, measurement of selected indoor pollutants etc. It should be taken not only after completion but also after the building has been in normal use.

C15 Enforce operation and maintenance personnel qualifications and testing. Operation and maintenance personnel should be well qualified and periodically examined/educated.

C16 Enforce regular maintenance and inspections of systems. Maintenance and inspection of ventilation systems should be done in regular intervals. Maintenance and inspections should among others include filter replacements, balancing (re-balancing) of the system.

C17 Enforce education (qualification) for HVAC designers. Education of design engineers and installers should include the elements mentioned in this guideline. There is a need for constant post-educational process to improve skills and qualifications of professionals. Designers should all be well aware of the potential IAQ problems and shall be able to find problem solutions which fulfil requirements in performance based ventilation and energy regulations.

C18 Easy to operate, access, and maintain solutions of HVAC systems. Design solutions of HVAC systems shall be easy to operate, access, and maintain in order to reduce number of possible critical spots in the system and to diminish human factor responsibility for bad operation of a system.

C19 Ventilation system should be clean and kept clean. Ventilation systems can be a source of pollution if they are not clean. Possible pollutants that can deposit in ventilation system (such as dust, grease, microbes, mold, humidity etc.) can provide a refuge (environment favourable for survival and reproduction) for biological pollutants. These pollutants may be introduced into the indoor environment. In order to diminish this possibility, systems should be designed to allow access for cleaning, be cleaned in regular intervals and special attention should be paid to areas suitable for refuge.

C20 Automatic control should be easy to operate and should provide possibility to override by a user/occupant.

C21 Control the quality of products used for cleaning of ventilating system. Products used for wet and dry cleaning of ventilating systems should only be allowed for use if they do not represent a possible source of pollution after they are applied (e.g., do not continuously emit pollutants into ventilation system).

Table1. Occurrence of proposed guidelines in CEN documents

No	Guideline item	CEN document
A	**Avoid specific sources of pollution related to ventilation system**	
A1	Avoid uncontrolled condensation in HVAC components	EN 13053:2006 Para 6.2, 7.5
A2	Impose limits of noise generation by the ventilation system	EN 13779:2007 Para 7.6; App A.16 EN 15251:2007 Para 6.6: App E.1 CEN TR 14788:2006 Para 7.8
A3	Avoid air cleaning that produces ozone in the system	*EN 13779:2007 Para 6.2.3 states the opposite, that O3 is not dangerous*
A4	Control the quality of materials used in ventilating systems	
A5	Enforce minimum distances between outdoor pollution sources and fresh air intakes	EN 13779:2007 Para 6.2.3; App A.2.2 - A.2.4 CEN TR 14788:2006 Para 8.2.1
A6	Capture and remove pollutants at source	EN 13053:2007 Para 7.5
A7	Avoid adiabatic humidification and cooling	
A8	Regulate leakage of exhaust or extract air duct systems	EN 13779:2007 App A.8
B	**Reduce exposure to pollutants with ventilation**	
B9	Determine ventilation rates to reduce concentrations of pollutants originating from building materials and occupants activities to acceptable levels	EN 15665:2009 Para 5.4 EN 13779:2007 Para 7.4.2; App A.15 EN 15251:2007 Para 6.3; App B CEN TR 14788:2006 Para 7.1
B10	Provide always ventilation to meet IAQ requirements	EN 15665:2009 Para 5 CEN TR 14788:2006 Para 5.1
B11	Filter outdoor for ventilation and circulated return air. Removal efficiency and stages of filters should be adequate to air quality	EN 13779:2007 Para 6.2.3; App A.3.2 EN 15251:2007 Para 6.3.3 prEN 779:2011 Para 6 CEN TR 14788:2006 Para 7.5
B12	Avoid leakage of soil air into living spaces in order to prevent enhanced radon concentrations	EN 13779:2007 Para 6.4; App A.10 CEN TR 14788:2006 Para 6
B13	Control air distribution in building and rooms	EN 13779:2007 App E
C	**Operation and maintenance**	
C14	Enforce commissioning of the system	*commissioning described in EN 12599*
C15	Enforce operation and maintenance personnel qualifications and testing	
C16	Enforce regular maintenance and inspections of systems	EN 15239:2007 EN 15240:2007
C17	Enforce education (qualification) for HVAC designers	
C18	Easy to operate, access and maintain solutions of HVAC systems	EN 13779:2007 Para 5.10; App A.13 EN 12097:1997 Para 4.1 EN 13053:2007 Para 7.2 CEN TR 14788:2006 Para 7.4
C19	Ventilating system should be clean and kept clean	EN 13779:2007 Para 5.10; App A.14 EN 15239:2007 Para 4.2.1, 4.2.2 prEN 15780:2008 - whole standard CEN TR 14788:2006 Para 7.4, 8.3.1.2
C20	Automatic control should be easy to operate and should provide override possibility by user/occupant	CEN TR 14788:2006 Para 8.3.1.1
C21	Control the quality of products used for cleaning of ventilating system	

PROPOSED GUIDELINES IN CEN DOCUMENTS

Each of the 21 items in of the descriptive guidelines was checked for occurrence in existing CEN documents, which included European Standards (EN), draft European Standards (prEN), and CEN technical reports (TR). Table1 shows in which CEN documents the proposed item of the guideline was already discussed to certain extent. As it can be seen, most of the proposed guidelines items are in some form already expressed in different CEN documents. Before any of the items are included in the CEN documents the working groups for the standards are requested to review the scientific and practical evidence of the importance of the items included in the standard.

EFFECT OF EPBD 2010 ON VENTILATION SYSTEMS

The 2010 recast of the Directive on Energy Performance of Buildings (EPBD) requires among others that all new buildings in the EU are built as nearly zero energy by 2020. The HealthVent project collected data from 17 countries to get an overview of expected changes in ventilation systems due to the recast EPBD. The data covered geographically all parts of the Europe. Summary of findings, which are described in detail in [2] and [5], were:

- A very probable scenario is that in order to limit overall building energy consumption, ventilation rates will be reduced.
- IAQ related problems are expected to increase due to the tighter building envelopes and because requirements for the IAQ quality are not included in the EPBD. On the other hand, slightly less than half of the respondents think that IAQ will increase due to revised ventilation regulation to tackle the IAQ problem.
- Majority of the respondents expect ventilation regulation to be revised in the near future. The rest do not expect their regulations to change soon because they have recently been revised.
- The opinion about the future enforcement of ventilation is split evenly with one half foreseeing regulation to be enforced less and the other half to be enforced more.
- According to the opinion of the majority, the future use of natural ventilation will decrease and the use of heat recovery will increase.
- Building envelopes will almost certainly get tighter.
- Majority thinks that IAQ will be for sure or probably included in future ventilation regulations with only 10% meaning that it will not be included.
- Most of the countries do not allow for possibility of reducing ventilation rates if less polluting materials are used and also do not allow to control ventilation rates based on the outdoor air quality.
- Reduction of ventilation rates if ventilation efficiency is improved or if effective room air cleaning is used is also not possible (and is not foreseen) in almost all countries in the survey.
- All the respondents think that demand controlled ventilation and heat recovery will be used in the future. A vast majority thinks that the technology to adjust ventilation rates based on the pollution loads and actual need will be used if the future.
- Two thirds of the respondents also think that ventilation rates will be adjusted with ventilation efficiency in the future.
- Use of heat recovery in hot climate is not expected to increase.

DISCUSSION

The final health-based ventilation guidelines to be developed in the HealthVent project will include descriptive part. They will be developed considering observations of indoor air quality and health problems related to ventilation systems in existing buildings and taking into account recommendations of the current standards and codes. The descriptive guidelines outlined above have got many advantages and disadvantages, as described in the following:

Advantages:

- Descriptive guidelines clarify the general principle of air hygiene: avoid exposure to pollutants
- Descriptive guidelines represent requirements that a ventilation systems should meet for a good indoor air quality.
- Descriptive guidelines are focused on good performance of ventilation and on preventing system malfunctions which would lead to reduced exposure to pollutant.
- Descriptive guidelines are operational, i.e. they can be applied in practice and implemented just after the publication.
- Descriptive guidelines are universal and can be applied to any type of ventilation system or technology used where problems occur. They are independent of factors like emission scenarios, climate and geography, etc.
- Descriptive guidelines are attainable using existing technology and methods of ventilation.
- Descriptive guidelines are based on actual scenarios where certain ventilation technique was applied and its efficiency for reducing health risk was measured.
- Descriptive guidelines are applicable in all types of buildings where ventilation systems are present.

Disadvantages:

- Descriptive guidelines do not relate health effects directly to any specific or actual pollutants. They are based on risk management.
- Descriptive guidelines do not characterise exposures and do not have markers of exposure.
- By simply using descriptive guidelines the required level of IAQ cannot be assured. They have to be supplemented with guidelines prescribing ventilation rates (quantitative guidelines).
- Descriptive guidelines handle the properties and potential problems in existing ventilation systems but not for possible future systems, if new or advanced.
- Because of the constant development of technical features of mechanical systems descriptive guidelines will have to be regularly updated.

CONCLUSIONS

European Standards, if properly applied, should already ensure no problems with ventilation systems (good practice). They already cover a significant part of the elements which are included in the descriptive guidelines presented here. These standards are however not often followed in practice as they are not mandatory unless referred in the national or EU codes. National building regulations and codes regarding ventilation on the other hand include only few of the elements of the descriptive guideline outlined above. The descriptive guidelines described in the present paper if adopted would minimize health risks from unnecessary exposures associated with improperly operated and maintained ventilation systems. Harmonized regulations would benefit industry by i.a. reducing the construction cost of ventilation systems.

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THE ROLE OF STANDARDS TO IMPROVE THE QUALITY OF VENTILATION SYSTEMS

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ABSTRACT
The use of European standards plays an increasing role in the design and dimensioning of ventilation systems. Beside definitions and products test methods, with an important impact on the quality of products through well defined measurements that makes it possible to compare and rely on announced characteristics, the ventilation standards - and especially the European standards - have proposed criteria, calculations procedures, assumptions and standard conditions to use the performance characteristics of products in a whole ventilation system.
Controlling the result in situ, making recommendations for handover, for cleaning possibility, maintenance and survey, inspection and proposals for improvements are also contribute to the actual quality of ventilation system and their sustainability. Ventilation standards can play a key role in final quality of ventilation systems.

KEYWORDS
Ventilation, standards, system, product, design, dimensioning

INTRODUCTION
The CEN TC 156 – “Ventilation for buildings” covers both product standards and system standards. This situation allows ensuring the consistency between the two families: the same experts handle the definition and measurement of characteristics and their use afterwards. Product standards are always a compromise between useful characteristics and possible measurements, laboratory methods and results and their transcription for availability and reliability in the “real world”. The challenge is to successfully go from available, reproducible product characteristics to accurate impact of the products on the system.
Indoor air quality, noise, comfort, energy impact, installation, maintenance… ventilation products and systems face many challenges that will result in the global concept of “quality of the ventilation systems”.
The corpus of standards from criteria, design, dimensioning … to handover, commissioning and maintenance through testing, rating, fitness for purpose … has a key role in the final quality of ventilation systems.

VENTILATION SYSTEM
I am involved in the European ventilation standardisation work for almost 25 years now. One of our first works was to understand each other: “ventilation” did not have the same meaning for an English, a French, a Swedish … “System” … needed several days (yes, … days !) to come to a sort of agreement.
The first merit of TC 156 is to have proposed from the very beginning (WG1) to work on a common list of terms and definitions. Of course this has not a very direct impact on the quality of the ventilation systems! This has to do however with the common acceptability of what is ventilation, what is a system and what is quality: without this common vision and common definitions we would not discuss today of the impact of standards on this topic … by the way, I am not sure that “quality of ventilation systems” is clearly defined!

ventilation system	Combination of the ventilation installation and the building itself.
ventilation installation	combination of all components required to provide ventilation
Ventilation	designed supply and removal of air to and from a treated space
treated space	enclosure served by an air distribution system

Table 1: definitions from EN 12792.

Although there is a sort of loop on the word “system” it can be noticed that, from the beginning, the ventilation system includes the building … 20 years after, the impact of the building leakage is finally taken into account in some national regulations (not all) … mainly for energy reasons!

The EN 14788 – “Design and dimensioning of residential ventilation systems” did propose limitations in the use of technologies (Exhaust only, Demand Controlled Ventilation or Heat Recovery Ventilation Units) depending on the leakage level of the building and its shielding.

A simplified approach was given to limit the effect of infiltration to 25% of the designed ventilation, and for HRVU to limit the extra energy cost of these infiltrations to 25% of foreseen energy costs.

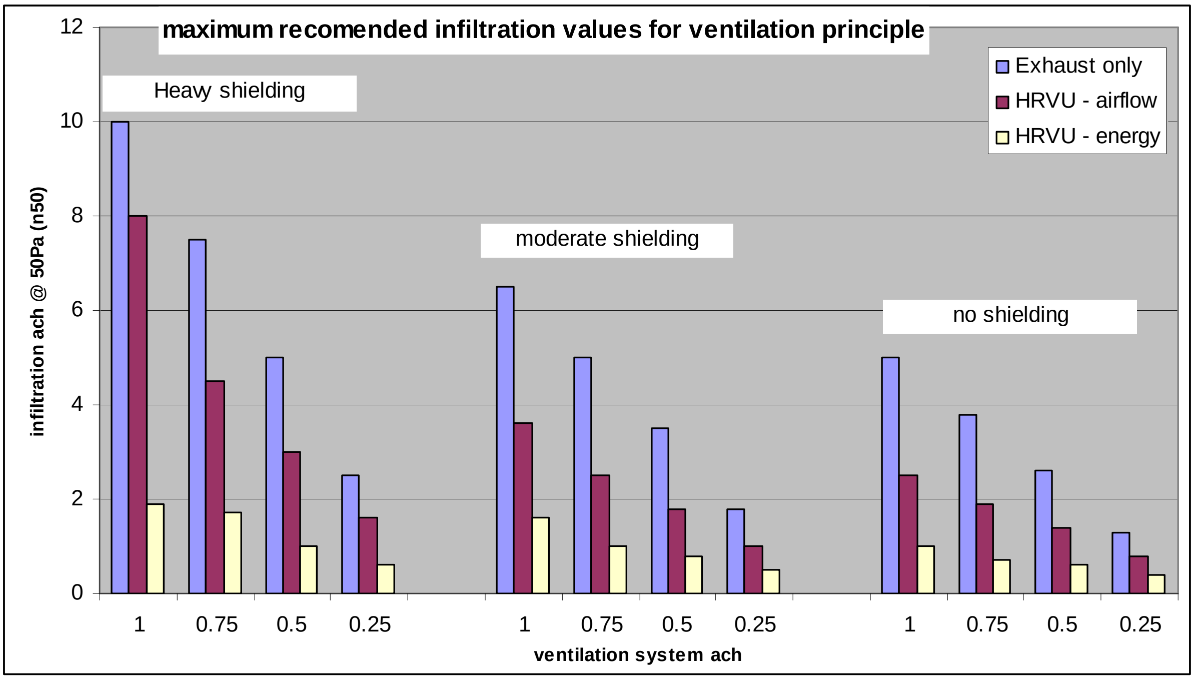


Figure 1 : maximum n50 to limit the infiltration to 25% of ventilation airflow from EN 14788 (2004).

It was an attempt, from the standard, to propose a result oriented method and to address a real issue without giving absolute values (non harmonised standards are not regulations). This approach was simplified but introduced (in an informative annex) a real concern about the complexity of interactions between ventilation installation (principle and collection of products) and ventilation system (ventilation installation in the building). We can consider that the standard had a proposal for improving the quality of the ventilation systems.

In this example, it is clear that the standard went far beyond the existing regulations and this proposal has not been reproduced on the superseding standard. The whole paragraph being criticized as not “standard” but guidelines from some countries, it has been removed.

The boosting role of the standard towards improved quality of ventilation system has been seen here as an attempt to challenge the national regulations and to introduce new obligations in the building codes … which it was not really: it was more an incitation to consider the issue in a very soft manner trough an informative annex.
Up to now very few regulation or national standard make a link between the ventilation principle and the adequate leakage level of the building. (or air tightness level …).

VENTILATION PRODUCT STANDARDS
Regarding the product standards the move towards better quality concerns ventilation installation primarily, thus ventilation systems according to the definition. The testing standards are the basis of information used both in design and dimensioning and in commissioning and maintenance.

EN 13141-7 is about "Performance testing of a mechanical supply and exhaust ventilation units (including heat recovery) for mechanical ventilation systems intended for single family dwellings". This standard is one of a long list (EN 13141-1 … -11) dealing with residential ventilation products. It provides measured information on aerodynamics, acoustics, thermal efficiency and electrical consumption and information from the manufacturer on essential topics.
The first interest of having such standards is obviously to make possible the fair comparison between different products and manufacturers. The second is to have complete information during design and dimensioning phase. Another "hidden" interest is that the measurements are clearly defined, with their accuracy and limits, with their corrections and the conditions for them; sometimes with the limit of acceptation … the reliability of the information in its use by the designer is ensured.
At this point we can notice that a number of national certification schemes do not take all the test standard, or keep the principle but change some values, or simplify some methods, …they often claim using the EN 13141-x –y, they don't! This may seriously interfere with the reliability of the result.
The thermal efficiency of a heat recovery ventilation unit is difficult to measure and the temperature, humidity, pressure conditions are of primary importance. It has been decided in this standard to limit the possibility of giving a value to the efficiency if the internal leakages were too high (5% or 10% depending on the position of the fans). This limit has been given from a quality of measurement point of view (accuracy of thermal balance not achievable) but heavily participates to the quality of the product itself: in France only few products did comply with this level of exigency before the use of the standard … and they had obviously a recovery efficiency value announced! The products have been improved and now comply with the demanded leakage level.

EN 13142 is a useful complement of the EN 13141' series: it describes how the product shall be tested if the description may be interpreted: the text is general but fits for every particular product: air inlets, exhaust grilles or even heat recovery units:

"EN 13142
4.1 General
It is essential that the results of product performance tests reflect the performance which will be achieved by the product in service. A product shall therefore be tested as a complete assembly with all necessary components which affect performance. Accessories are sometimes available for a product as an option. Where accessories could affect performance, the product shall be tested both with and without those accessories. If any insect screen, filter

or similar device is intended to be fitted to the product, then it shall be in position when the product is tested."

This general assessment has been written to avoid misleading in some commercial brochures: the flow is given without filter (presented as an "option") but the pressure loss of this filter is so high that the flow is divided by 2 or 3 at the same difference of pressure … the test is conducted with a G4 filter, but the marketing draws the attention to the availability of F7 filter and the resulting purity of the air … Once again the standard tries to put in parallel the measure and the use of the product, and to have the entire information for design and dimensioning: the resulting ventilation system will not really be "improved" but "conform to the specifications" where it could have been working in a deteriorated mode.

VENTILATION PRODUCT - SYSTEM STANDARDS

An example of intermediate standard is the EN 12097 –"Requirements for ductwork components to facilitate maintenance of ductwork systems". Its scope begins with:

"This European standard specifies requirements for dimension, shape and location for access panel for cleaning and service in ductwork systems…"

As we can see it is a standard that deals with products with the purpose of having an effect on the system. The cleaning possibility of ductwork, especially for supply ventilation is an essential requirement as many studies have proved that the ductwork itself can be a major source of pollution: the intention of the standard is to ensure that the fitness for purpose of this subsystem (ductwork) will remain during its lifetime – which can be 30 to 50 years. This standard gives clear requirements on principle and means for the cleaning of ductwork,

"General requirements

The air distribution system shall be designed, manufactured and installed in such a way that cleaning of internal surfaces and components is possible. The design and installation documentation shall indicate by dimensions the location of all access components and provide details of the size and type of component required. The documentation shall also indicate the location of components mentioned in 4.3 to enable proper service and re-adjustment.

The cleaning method may vary depending on the category of the air distribution system. The arrangements for cleaning depend on the category of air system, as specified in EN 13779. This category influences the frequency of access covers, the method for cleaning and the cleaning intervals. …"

Although these general requirements are not very technical they represent a clear improvement for installation and maintenance, they are a clear basis for contracting and thus for getting proposals not for comparable initial design and dimensioning but with the addition of maintenance availability which is a guarantee of long term reliability and important element for decision (not only lowest price but best bidder compared to others on a global basis). To avoid having only general requirements (not so binding in real life) they are completed with precise requirements for some applications:

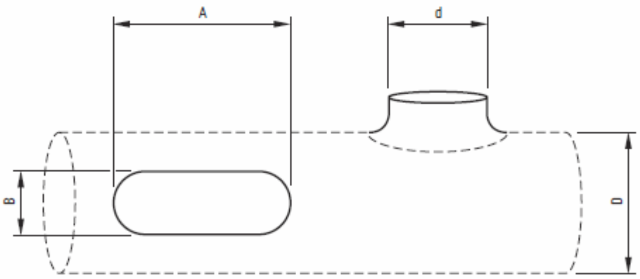
4.2.2.1 Openings for rigid circular ducts

For cleaning access the ducts shall be provided either with openings of sizes according to table 1 or T-pieces with removable end caps with a minimum nominal diameter (EN1506) according to table 1.

Table 1 — Access panels in circular ducts, minimum dimensions

Rectangular or oval opening		Branch/T-piece + end cap with minimum diameter	
Duct diameter nominal (mm) D	Minimum dimensions of openings in duct walls (mm) A x B	Duct diameter, nominal (mm) D [a]	Nominal EN 1506 male dimension or minimum opening (mm) d
100 ≤ D < 200	180 x 80	100	100
200 ≤ D ≤ 315	200 x 100	125	100
315 < D ≤ 500	300 x 200	160	125
500 < D	400 x 300	200	160
		250	200
		315	250
		400	315
		500	400
		≥ 630	500

[a] For additional sizes the requirements of the nearest larger nominal size apply.



4.4 Location and frequency of access panels
The ductwork shall be equipped with sufficient access panels in order to ensure that no part of the ductwork is located with more than:
a) one dimensional change from an access panel;
b) one change of direction of more that 45 ° from an access panel;
c) 7,5 meters of duct from an access panel

With only a few requirements from the standard most of the needs for maintenance and cleaning are covered and provide a clear improvement of the ductwork system, thus the ventilation system.

The EN 12097 is completed by EN 15780 “Ventilation for buildings - Ductwork - Cleanliness of ventilation systems”:
“1 Scope
This European Standard applies to both new and existing ventilation and air conditioning systems and specifies the assessment criteria of cleanliness, cleaning procedures of these systems, and the validation of the effectiveness of cleaning (…).
Considerations for change of component as an alternative for cleaning (e.g. in case of flexible ducts and air filters) are also included. This European Standard specifies general requirements and procedures necessary in assessing and maintaining the cleanliness of ducted ventilation, including:
- *cleanliness quality classification;*
- *how to assess the need for cleaning (visual, measurements);*
- *assessment frequency (general guidance), guidance of system inspections in accordance with EN 15239, …*

 selection of cleaning method – to be in line with handing over documentation according to EN 12599;
 how to assess the result of cleaning.
(…)"

The corpus of these standards consists in a comprehensive and consistent pack for improved quality of the ventilation ductwork system, from handing over to maintenance and inspection.

VENTILATION SYSTEM STANDARDS

The system standards have to find their way between two stumbling blocs: they are not guidelines, they are not regulation. The fact is that in some countries the standards play a role close to regulations … If the writing is too loose it may not be applied, it can be refused as a standard (normally the verb to use is "shall" and never "should") from those countries willing clear position. If the writing is too direct, it can be refused from those countries who do not want to change their existing standard …

"National regulations shall always be followed, even when they deviate from requirements given in this standard."(EN 12097)

Ulysses: Charybde and Scylla or: Standard finding its way between Regulation and Guidelines

The problem is simple for product standards but system standards are always close to one or other border, especially if they want to propose a solution for an identified issue: most of the time it is solved by the use of informative annexes or default value, default method … This situation is often criticized as not being part of a standard (and progressively disappearing in today's redaction).

EN 13779 –"Ventilation for non-residential buildings – Performance requirements for ventilation and room-conditioning systems" This standard is clearly focusing on system:

1 Scope

This European Standard applies to the design and implementation of ventilation and room conditioning systems for non-residential buildings subject (…) It focuses on the definitions of the various parameters that are relevant for such systems.

The guidance for design given in this standard and its annexes are mainly applicable to mechanical supply and exhaust ventilation systems, and the mechanical part of hybrid ventilation systems. (…)

The classification uses different categories. For some values, examples are given and, for requirements, typical ranges with default values are presented. The default values given in this standard are not normative as such, and should be used where no other values are specified.

Classification should always be appropriate to the type of building and its intended use, and the basis of the classification should be explained if the examples given in the standard are not to be used.

The use of "shall" is extensive in the normative part … but mainly concerns the definitions and the list of items to consider when designing a ventilation system:
"… The description of the characteristics of the environment and the structure of the building shall be obtained for design. The desired results required at the time of hand-over and during normal operation shall be specified and documented ..."
"… Information shall be given on climatic environment; as a minimum, design conditions for winter and summer are required ..."
"… The occupancy level shall be given as schedule …"
"… The ventilation rate for human occupancy shall be determined using the information in 6.2.5 or by using specific values for the airflow rate based on regulations …"

Most of the "shall" are related to the relationship between the actors of the construction, from early design to use. This is perfectly written in the standard:
"5 Design criteria
(…) The design criteria specify the information needed to design the system. These criteria also constitute the basis for the measurements that will be carried out during the hand-over process. They provide the common language between all the parties including the client, designer, contractor and the operation and maintenance personnel ..."

In this respect, this standard is not really a system standard with a direct impact on the final quality of the ventilation system: the normative part gives the structure to define and share responsibilities.

Interesting are the informative annexes:
Annex A Guidelines for good practice.
Annex B Economic aspects.
Annex C Checklist for the design and use of systems with low energy consumption.
Annex D Calculation and application of Specific Fan Power (…) SFP, SFPE, and SFPV
Annex E (informative) Efficiency of ventilation and air diffusion.

No "shall" in this section, only "should", "recommended", "may" … for essential items related to the quality of the ventilation system: most of them are expressed in existing regulations: Position of intake, discharge, limits for pollutants, proposal for filter categories, impact of buildings' air-tightness, extract rate values, pressure loss, air-tightness of the ductwork, insulation of the ducts, maximum vertical size of a zone, pressure conditions, demand controlled ventilation, designing low consumption system, spec requirement for maintenance, noise, … As a whole the standard can be used in improving the ventilation system, more directly from its informative part than from its normative part.

For residential ventilation EN 15665 – "Determining performance criteria for residential ventilation systems" plays a special role as it is designed for regulators:
"Introduction: (…)
This document is not intended to design and/or dimension a ventilation system.
This document intends to support any National regulation.
This document is intended to give guidance to those with responsibility for producing requirements and standards for residential ventilation systems.

It is recommended that future revisions of relevant regulations and standards should consider the content of this document. (…)"

Rather than trying to give any value or impose any method, it proposes a limited number of methods, from very simple (single value) to more complex one, associated with a yearly calculation, and asks the regulators (shall) to use one of them. The idea is to prepare common basic rules for national regulations and to avoid other local approach which tends bursting the regulations rather than making them become closer. The ventilation system is taken into account from its results on the quality criteria (IAQ, noise, comfort, energy, …) but the word "system" is not completely in line with the EN12792: the products are not dealt with.
The ventilation systems should be better with the use of EN 15665 because of the impact on their design criteria and their assessment.
"Scope: (…)
This document sets out criteria to assess the performance of residential ventilation systems (for new, existing and refurbished buildings) which serve single family, multi family and apartment type dwellings throughout the year.
This document specifies ways to determine performance criteria to be used for design levels in regulations and/or standards. (…)"

CONCLUSION
In almost all countries, studies have shown – and sadly still show – an impressive list of quality problems from the ventilation system: design, installation, maintenance … most of them could be avoided by using the standards.
This is the most important issue for ventilation industry as the products, their installation and their maintenance are more and more crucial: the trends are clearly a better air-tightness of the buildings and an increasing complexity of the products. For long the problems have been compensated by the leakages, this will not be true in the coming years and any failure of the system will result in IAQ or noise problems (hence complains).
This is a booster and great opportunity for the complete ventilation industry (designers, manufacturers, installers, maintenance, …) but also a big threat if some weak link remains. The use of standards and their annexes is a guarantee that the biggest mistakes will be avoided and the products will be used and installed in a correct way.
Keeping in mind that the ventilation system includes the building is also a key issue, the fit between ventilation installation and the building air-tightness should always be taken in account when prescribing a solution.
Last issue, we often speak of quality/price ratio, we should consider also complexity/use ratio, the ventilation system is to be used and maintain by the user or a Service Company: the resilience of the system against a weak maintenance should play a role in the decision. This last issue is not (not yet …) considered at its right level in standards or regulations.

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- Part 2: Exhaust and supply air terminal devices.
- Part 3: Range hoods for residential use.
- Part 4: Fans uses in residential ventilation system.
- Part 5: Cowls and roof outlet terminal devices.
- Part 6: Exhaust ventilation system packages used in a single dwelling

- Part 7: Performance testing of a mechanical supply and exhaust ventilation units (including heat recovery) for mechanical ventilation systems intended for single family dwellings.
- Part 8: Performance testing of un-ducted mechanical supply and exhaust ventilation units (including heat recovery) for mechanical ventilation systems intended for a single room.
- Part 9: Externally mounted humidity controlled air transfer device.
- Part 10: Humidity controlled extract air terminal device.
- Part 11: Supply ventilation systems.

[2] EN 13142 Ventilation for buildings — Components/products for residential ventilation — Required and optional performance characteristics.

[3] TR 14788 Ventilation for buildings — Design and dimensioning of residential ventilation systems.

[4] EN 15665 Ventilation for buildings — Determining performance criteria for residential ventilation systems.

[5] EN 14134 Ventilation for buildings — Performance testing and installation checks of residential ventilation systems.

[6] EN 15241 Ventilation for buildings — Calculation methods for energy losses due to ventilation and infiltration in buildings.

[7] EN 15242 Ventilation for buildings — Calculation methods for the determination of air flow rates in buildings including infiltration.

[8] EN 12097 Ventilation for Buildings— Ductwork— Requirements for ductwork components to facilitate maintenance of ductwork systems.

[9] EN 15780 Ventilation for buildings - Ductwork - Cleanliness of ventilation systems.

[10] EN 13779 Ventilation for non-residential buildings – Performance requirements for ventilation and room-conditioning systems.

[11] EN 15239 Ventilation for buildings - Energy performance of buildings - Guidelines for inspection of ventilation systems

QUALITY ASSURANCE OF VENTILATION SYSTEMS IN RESIDENTIAL BUILDINGS: IS CERTIFICATION AND/OR (RETRO-) COMMISSIONING THE ANSWER?

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ABSTRACT

Product standardisation and building system standardisation are the basis for certification of products and services. Manufacturers of residential ventilation products should set up certification schemes according the CEN and ISO standards to assure quality to their client.
European based accredited certification schemes like Eurovent certification should have the preference. Developing the product standards under the Ecodesign directive and the EPBD requires a harmonised approach where the output of the product standards is suitable as input for the system standard procedure.
Quality Assurance by certifying products is a first step. A necessary second step is to certify the design/installation process for ventilation systems on basis of EN45011. This is an effective way of QA of installers. Commission schemes may offer a solution as well.

Product certification

Product certification is essential to assure the overall performance and energy performance of buildings. Designer and consultant pay a lot of attention to select, project and install HVAC&R products as part of heating, ventilating, air-conditioning and cooling systems in buildings.
They have to base their selection on the data presented by the producer or supplier of these products. The system designer or installer has to be sure that these data are reliable and applicable. The building system or sub-system will only perform according to the expectation and connected contract obligations if the product data are correct and complete.

Who to blame if the ventilation system doesn't perform?

If at the end the building or building system doesn't perform according to the agreed design specifications, who is to blame?

- The designer because of a poor design?
- The installer because of poor installation work?
- The supplier of the integrated products because of poor performance of these products?

Given the fact that the installer is in many cases the subcontracting party, it is the installer who gets the blame. For the client this is simple, the installer installs and should perform. As professionals in our field we know that this may be client's logic, but is very often not correct. The contracted installer may not be paid or be responsible for the design. Should he have checked the design or the correct performance of the products? Is he to blame if he trusted the inaccurate or unreliable product data? How could an average installer ever win a dispute on this issue when opposing a specialized producer?

The reliability level of product certification

Given these many questions it seems logical that a substantial number of reliable producers in our field agreed to choose for the certification of their products. With certified products they want to convince their clients that the performance data of their products are reliable.

This product certification is a substantial step in the right direction. But are all certificates the same? Self-declared schemes, generally indicating that the producer is ISO9000 or ISO9001 certified may help but are less trustworthy as 3rd party certification schemes.

With this 3rd party certification where independent accredited certifiers declare that the declared product performance is reliable according to a specific, publicly available and by the accreditation body accepted certification guide and or standard.

In our industry there are organizations like Eurovent Certita Certification organizing this certification service on basis of certification schemes like ISO17025 [1] and EN45011 [2].

Their certification schemes are accredited (by one of the EU-Accreditation Bodies) and they refer to accredited laboratories testing the products. This is the best solution to build an affordable certification scheme. See also The Rehva European HVAC Journal, March 2013, www.rehva.eu .

Certifying the designer/installer of residential ventilation systems.

A next step for our HVAC sector could be certifying the designer and installer according to an EN45011 based certification scheme. This means that a contractor or client can choose for a certified installing company where the quality assurance is guaranteed by the system that requires regular 3rd party checks of the projects of this certified supplier (installer etc.). These schemes will generally be developed for specific application fields. They will also include the use of certified products. Making use of certified products makes it more efficient for the certified company providing the working installation. In this case he can trust the product certificates and doesn't have to bear this responsibility and doesn't have to check these products again.

It is important to give preference to certified products by promoting this to the client. The contracts should require this, if not we don't have a levelled playing field; since non-certified products may often be cheaper.

Make the product standards suitable to support system performance description and certification.

Product certification should focus on the information (data) requirement of the system designer/installer, report all data needed for good design and installation work. The Ecodesign directive requires more data of these products in the near future. This could be an opportunity for the further development of certification schemes. For products having impact on the energy performance of buildings, the EC (Mandate 495 [3]) will make them aware that the systems and product standards developed have to be in line with the EPBD procedures under Mandate 480 [4].

In discussions in product TC's (at CEN or ISO level) there is a first priority for just specifying the data to compare products. In doing so the market seems well regulated. System designers need more data that are not always visible in the product declaration; they have to rely for these data on the producer self-declaration and documentation. Product certification will become more welcomed by the system designer if a more complete product declaration is supported. To refer to the TC responsible for the product standard is not a good excuse, it is well known that non-producers are a minority in WG's developing these product-standards and don't have sufficient means to support the extension of the standards towards design information.

Is commissioning and/or retro-commission another route?
ASHRAE Guideline 0-2005 [5] defines commissioning as: "A quality-focussed process for enhancing the delivery of a project. The process focusses upon verifying and documenting that the facility and all of its systems and assemblies are planned, designed, installed, tested, operated and maintained to meet the owner's Project Requirements."
In most cases this commissioner, or as they say, the commissioning authority, is an independent entity not being the planner/designer/installer/tester/operator/maintainer. This may be a good solution for extensive complicated and sometimes risky projects, but seems overdone for the majority of new and existing projects for small and medium sized buildings.
An EN45011 product/process certification scheme seems more attractive, lower costs and achievable for the majority.

Developing the product standards under the Ecodesign directive [6] and the EPBD [7] requires a harmonised approach where the output of the product standards is suitable as input for the system standard procedure.
Standards are the basis of certification or commissioning procedures. This is why I want to say a few words on the standard development on products and systems in Europe.
Among many, two EU directives (an EU directive is a basis for possible national regulation in EU member States) are important for the ventilation industry and the designers and installers of residential ventilation systems. Developing product and system standards related to Ecodesign and EPBD to support the implementation of these Directives require upgrade or development of ventilation products standards. Relevant product standard committees have to be aware that the performance data should be suitable for the system performance description under the EPBD. The availability of these standards will make the further development of product and system certification schemes possible.

There is an urgent need to use standardisation as a basis for Ecodesign Directive. In the past: the procedures developed under the earlier "lots" have not been well harmonised with the EPBD system standard approaches, this may not be acceptable for relevant stakeholders and these procedures are not expected to be accepted on CEN-TC level to become included in these EN and/or ISO product standards. We have to be aware that the possible overlap with EPBD work may lead to confusion in the process of revising the current set of CEN EPBD standards if product standard developers use different approaches.
The EPBD system TC's (like amongst others CENTC156) have to report to the relevant product TC's on the product specification necessary to describe the system performance. The product TC's have to refer to the CEN EPBD system standards if they want to use methods to determine the energy performance of the products in connection with the system.
CEN established an Ecodesign Coordination group to support this coordination.

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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-yourselves. 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.

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.

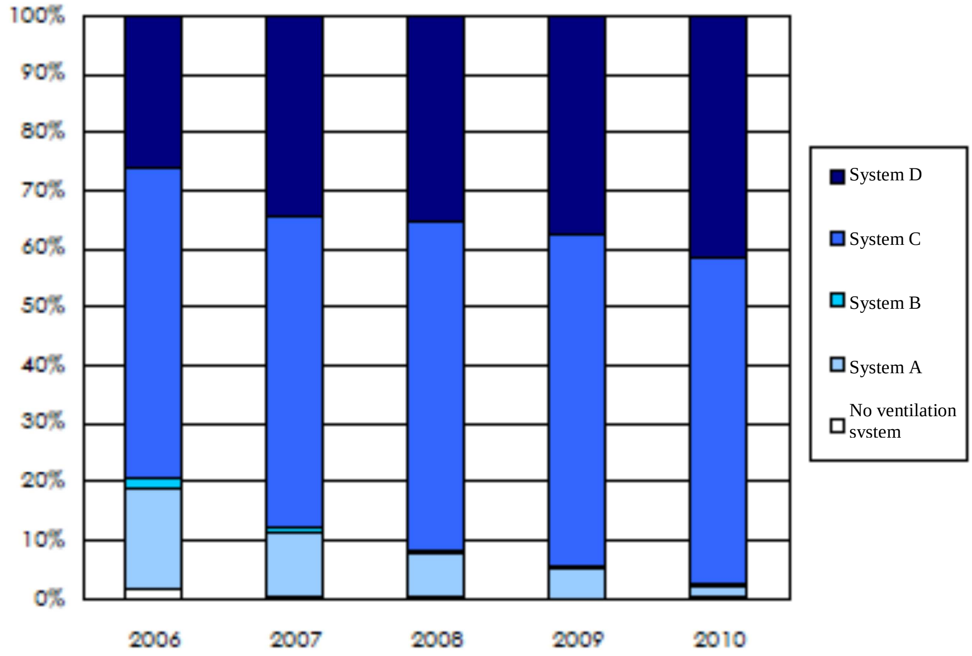

Figure 1: Market share in % of 4 systems in newly built dwellings 2006-2010. (VEA ref (1))

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), 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)

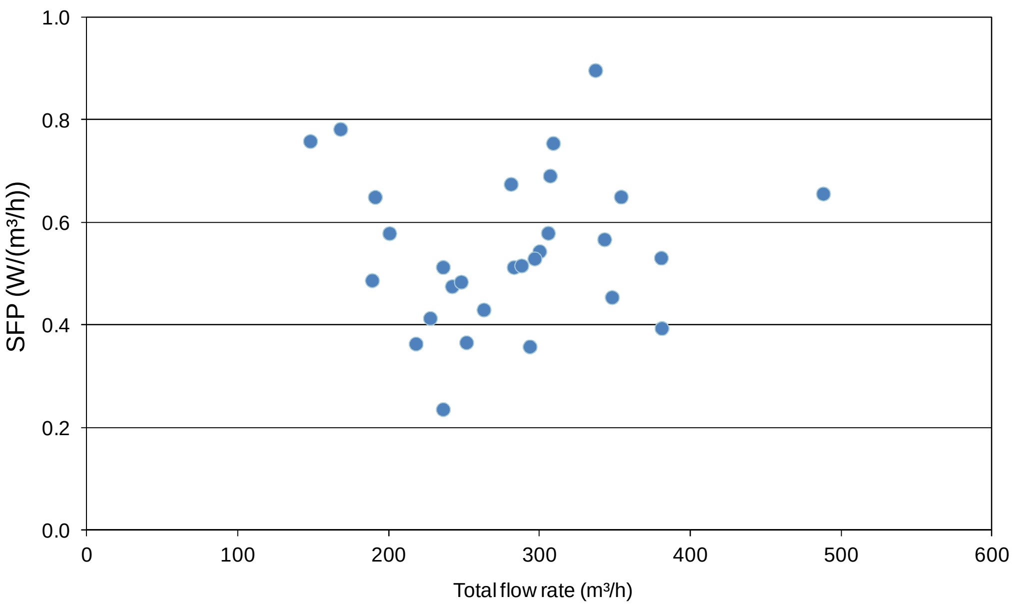

Figure 2: Measured specific fan power (SFP) for residential all mechanical ventilation systems at nominal flow rate (Caillou 2011)

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-FFC[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.

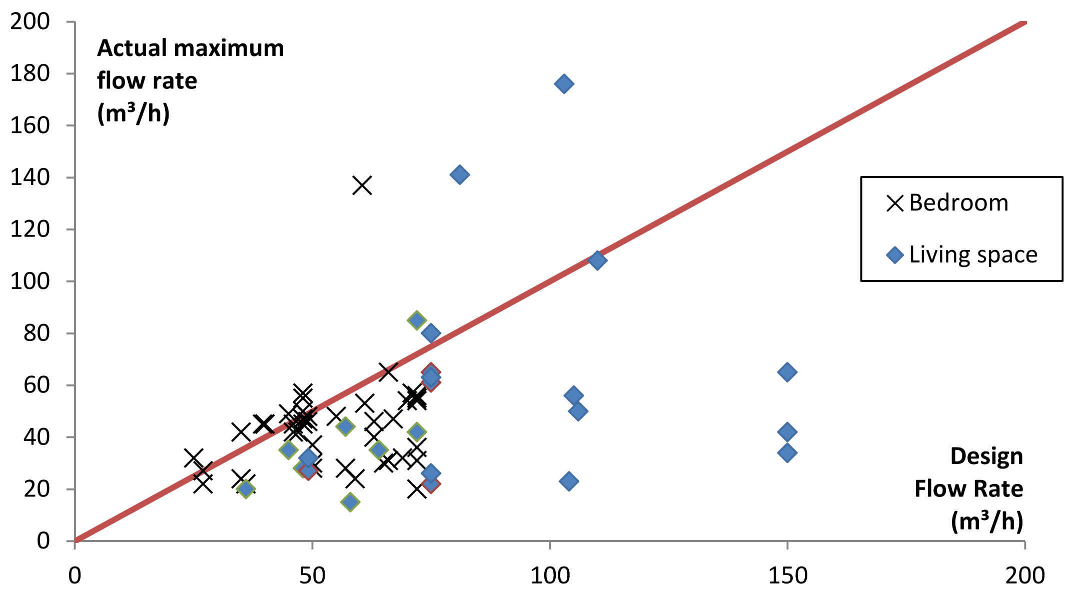

Figure 3: Measured flow rates at ATD vs. design flow rate ("Clean Air Low Energy- 2012")

[1] FVB FCC Constructiv: Fonds voor vakopleiding in de bouw: Organisation for training of construction labourers

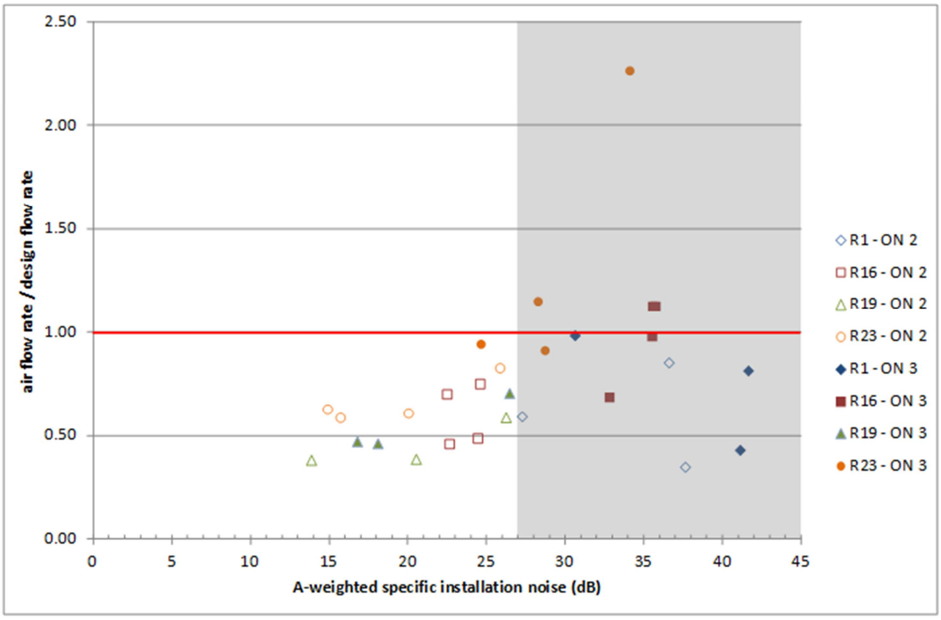

Figure 4: Ratio of air flow rate and design flow rate against the A-weighted specific ventilation noise levels for Clean Air Low Energy bedrooms (selection of available data), showing that when systems deliver the design air flow rate, the risk for noise nuisance increases (L > 27 dBA).

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/(m^3/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.

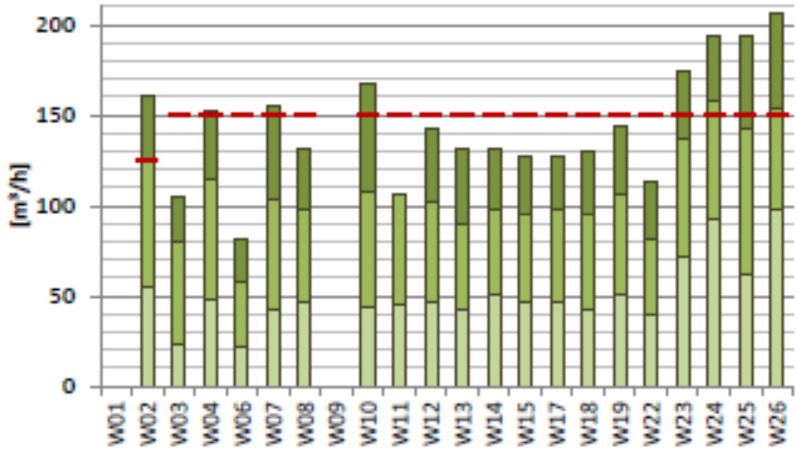

Figure 5: Measured total mechanical exhaust rates per dwelling, compared to minimal values in legislation. The bars reflect the measured exhaust flow rates at different positions of the fan control switch. (UGent campaign)

Topic	Major causes of quality problems	Existing quality schemes or incentives
Product	Reliable product information is missing	Available for some products, no further actions planned in the short term
Design	In most cases, insufficient design is performed (rules of thumb)	Quality scheme under development that requires design documentation and as installed performance based requirements
Installation	Insufficient design available, with as a result undersized systems, noise problems,… Ad hoc design modifications Cleanliness of duct system	Quality scheme under development that requires as-installed performance. Some manufacturers employ certified trained contractors
Commissioning	Neglected	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,…)
	Wrong measurement instruments and methods	Measurement methods as part of quality scheme
Maintenance	Neglected Insufficient information	 Maintenance information required by quality scheme
Inspections	Absent	No action taken

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.

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ON THE QUALITY OF RESIDENTIAL VENTILATION SYSTEMS IN CANADA

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ABSTRACT

The residential ventilation market in Canada is defined by the country's geography and jurisdictional landscape. Model codes and standards have been developed in Canada to unify the approach across the country, however due to the fact that building construction is a provincial/territorial jurisdictional matter, the "model" building code developed at the national level is adopted in whole or with variations/additions and enforced at the provincial/territorial level. Code provisions can be augmented at the municipal level in certain jurisdictions. This can lead to regional variations in code requirements, e.g. the predominant use of exhaust-only systems in Ontario.

The long heating season and cold winters have driven construction standards in Canada to produce air-tight buildings as a matter of course. Recently-issued model energy provisions for housing and small buildings (2012) assumed that the average air change rate per hour at 50 Pa for new build is 3.2 and that if an air barrier system is constructed to prescriptive requirements, an average of 2.5 air changes per hour could be assumed. Given these levels of air tightness were being achieved in some locations in the 1980's it became apparent that deliberate mechanical ventilation would be required. This need had been introduced into the 1980 edition of the National Building Code of Canada (NBC) but was refined and expanded through the 1995 edition (the code is updated on a five year cycle). In 1991, the mechanical ventilation standard (CSA F-326-M91) was published covering design, installation and commissioning, which is one of the acceptable methods to meet ventilation requirements for housing and small buildings.

The rate of new construction in Canada is such that almost 25% of single family housing stock has been constructed since 1990. Combining this with the code requirements for mechanical ventilation systems, it can be concluded that the residential ventilation industry is well developed and mature. Future refinements to residential ventilation systems will be made as our understanding of health and ventilation is further developed and as energy constraints become more pertinent.

KEYWORDS
Mechanical Ventilation, Canada, Residential

INTRODUCTION

Canada is the second largest country in the world (more than 9 million km^2 of land) with a population of only 33.5 million (Statistics Canada, 2011), most of who live in the southern urban centres; this coupled with the resulting variations in climate of such a large country leads to challenging requirements for building codes and equipment suppliers/installers. The general approach to ventilation is that standardisation takes place at the national/international level, certification/building code implementation is determined provincially/territorially and that cities/local governments can make further refinements if required by local policy/conditions.

Natural Resources Canada (a department of the federal Government) conducts regular surveys of residences in Canada to inform energy efficiency policy. The most recent data available is from 2007[1] (NRCan, 2007). The survey focuses on the provinces and thus there is no data for the territories (these are the northern areas of Canada: Northwest Territories, Yukon and Nunavut, combined population 110,000 or <0.5% of the total population). The distribution of households and dwelling types in Canada is shown in Table 1. As can be seen the majority of households are in Ontario (37%) and Quebec (26%), and are single detached, double or row houses (74%). This latter statistic is important as the NBC differentiates between 'small' buildings and all other buildings. Housing and small buildings that are fewer than three stories high and smaller than 600 m^2 in building area are regulated under Part 9 of the NBC. All other buildings require detailed engineering design and approval. The 2007 NRCan survey reported that 9% of single family homes were built after 2000 and 25% after 1990.

Table 1. Households/dwelling type in Canada (NRCan, 2007).

	Single detached	Double/row houses	Low-rise apartments	High-rise apartments	Mobile homes	Total
Atlantic provinces	728 212	70 338	84 844	-	32 872	941 738
Quebec	1 522 558	671 080	975 207	100 647	34 386	3 303 877
Ontario	2 735 817	816 413	456 393	776 286		4 794 437
Manitoba and Saskatchewan	590 127	51 321	144 226	-	19 170	839 356
Alberta	926 562	164 919	118 940	-	34 289	1 316 021
British Columbia	982 484	271 127	350 562	90 504	42 243	1 736 920
Total	7 485 759	2 045 197	2 130 172	1 098 734	172 488	12 932 350

This paper focuses on residential buildings that fall under Part 9 of the NBC. This part of the code is traditionally prescriptive to enable construction of houses and small buildings without the involvement of professionals and specialists (a particularly useful feature in remote locations). Increasingly, the requirements in the Part 9 are moving towards including a performance-based approach while maintaining the prescriptive compliance path. Since 1980 the NBC has required a mechanical ventilation system (initially only for houses heated with electric baseboards) and later extended to define/include a principal mechanical ventilation system with circulation throughout the house in 1995. The current requirements can be satisfied with a balanced or exhaust-only system (NRC 2011). Typically, the ventilation system is used in conjunction with a forced air heating/cooling system to ensure the required mixing of outdoor air throughout the house. Around half the houses in Canada have a forced-air system for heating (and maybe cooling) the home. Houses with other heating systems, conforming to the 1990 NBC, will require a dedicated ventilation system. Older houses are likely to not have a dedicated ventilation system.

Compliance checking for part 9 buildings is the responsibility for the AHJ (authority having jurisdiction), usually a municipal building/fire official. Typically the AHJ will make several visits to a construction site at key stages of construction – inspecting foundations, vapour barriers etc. before they are hidden by backfill, drywall etc. The AHJ has the final jurisdiction and can force builders to make changes to the construction if they are not satisfied that the construction conforms to the applicable code requirements.

1 Although the survey was repeated in 2012 data will only become available later in 2013.

Evolution of Code Requirements for Mechanical Ventilation

As mentioned above the need for mechanical ventilation in some Canadian homes was recognised in the 1980 NBC. At that time the ventilation concerns were limited to houses heated with electricity (a heating option that is still relatively common in parts of Canada where inexpensive electricity is produced by hydroelectric plants). This initial requirement was for exhaust only fans to be installed. As further research was completed on residential ventilation it became apparent that mechanical ventilation was required for all houses. A further insight was that a simple exhaust system was not sufficient for ensuring that an even air quality would be achieved and the code was further modified (the 1995 edition) to include a circulation system (ensuring that air was well mixed through all rooms in a home). In parallel to the exhaust and distribution of air in a home the requirements for air change rate were also refined. In 1985 the requirement was 0.5 ac/hr which was reduced to 0.3 ac/hr in the 1990 NBC. The requirements are now based on the number of bedrooms in the home.

Since 1995 only minor changes have been made to the NBC in terms of ventilation requirements: they have been made easier to understand, technical changes have been made to the integration of outdoor air supply in a forced air heating system so as to avoid premature deterioration of the heat exchanger, and to reduce the probability of excessive home depressurisation.

The Model National Energy Code for Houses was introduced to Canada in 1997 as a separate code (although energy performance of homes has been addressed for longer via voluntary programs such as R2000). The energy efficiency requirements for housing and small buildings were updated and integrated into Part 9 of the 2010 NBC in late 2012. The current Part 9 requires ventilation heat recovery of at least 55% and in some locations at least 60% (depending on the January design temperature) at the principle ventilation flow rate. The energy calculations further require that the ventilation system is operated for the same duration in the proposed and reference houses, specified as 8 hours per day at the principle ventilation rate. Future revisions may have a greater focus on energy requirements related to ventilation which will have to be carefully balanced against IAQ parameters.

Example field studies

Many field studies have been undertaken in Canada and a full review is beyond the scope of this paper. They have tended to focus on a particular issue/population group and either measure the ‘engineering’ parameters (ventilation rates, home air tightness etc.) or the ‘health’ parameters (VOC concentrations, particulates, respiratory health of occupants etc.). One recent study that measured both ‘engineering’ and ‘health’ parameters was conducted in the Quebec City area where the focus was on the link between ventilation and asthmatic symptoms in children (Aubin 2011). Findings from this study include a significant number of homes with measured air change rates less than the nominally code compliant value of 0.3 ac/hr and significant reductions in pollutants (formaldehyde and CO_2 concentration) and improvements in relative humidity through the use of heat recovery ventilator (HRV) or energy recovery ventilator (ERV) technology.

Other studies include:

- Gilbert et al (2006) who found relationships between measured ventilation rates and pollutant concentrations. Unfortunately no record was made of the ventilation system in each house.

- CMHC (2004) conducted a small field study focussing on exhaust only ventilated homes in Ontario. They found that despite the presence of IAQ issues the occupants did not operate the ventilation system as intended (the code required a switch labelled ‘ventilation fan’ which was to be activated by the occupants at the same time as the forced air systems circulation fan). In the same survey it was noted that HRV’s were present in about 16% of homes.

- Thompson et al (2009) conducted an open ended question style survey of participants at NRC’s 2008/09 Building Science Insight Seminar series (“*Single and Multi-Family Houses: Improving Performance Through a Systems Approach*”) and represented contractors, building inspectors and code officials at 15 cities across Canada. The survey was targeted at ventilation systems and asked “*In your experience which advice do you follow when designing/ specifying/ installing /inspecting a residential ventilation system?*”. The most frequent response was Building Codes followed by Contractor/Consultant, then ASHRAE and Manufacturer’s manual/training. When asked about alternate sources of information that they were aware of the most frequent response was ASHRAE followed by Building Codes.

RESIDENTIAL VENTILATION MARKET

The market for residential ventilation in Canada is dominated by mechanical systems due to the longstanding requirements of the building code. Every province and territory has adopted this requirement. This has resulted in the majority of current buildings being equipped with some form of mechanical ventilation system: balanced, supply only or exhaust only. Due to humidity concerns many older homes have exhaust only systems installed in their bathrooms.

The drive towards mechanical systems was generated by the high quality of residential air barrier installation (and resulting lack of infiltration). Figure 1 shows the improvement in air tightness in buildings for three locations in Canada over time. It should be noted that the source of this data was from a retrofit incentive program, therefore newer buildings and ones built to the requirements of labelling schemes may be underrepresented (e.g. R2000 requires a blower door test to be less than 1.5 air changes per hour at 50 Pa, NovoClimat is 2.5). The recognition of the lack of infiltration and resulting decrease in indoor air quality drove the Canadian market towards the ‘build tight/ventilate right’ approach.

The most common solution for ventilation is the use of a HRV or ERV. A Statistics Canada survey of approximately 15,000 households across Canada in late 2009 found that one quarter of households reported using a furnace fan or HRV to improve air circulation. This proportion increased to approximately 50% for homes built after 2005. The proportion also depended on location, with homeowners in Manitoba indicating a higher usage of HRV/furnace controlled air circulation (36%) compared to other provinces (eg. 17-18% in British Columbia and Nova Scotia). These devices provide balanced ventilation through the use of a supply and exhaust fan and are the preferred solution in many jurisdictions and labelling schemes (e.g. R2000, NovoClimat, EnergyStar). However the minimum requirement in the NBC is for exhaust-only ventilation.

Enforcement of regulations is the responsibility of the AHJ at construction time. Once installed ventilation systems are the responsibility of the homeowner and there are no code requirements applicable to the operation of the system.

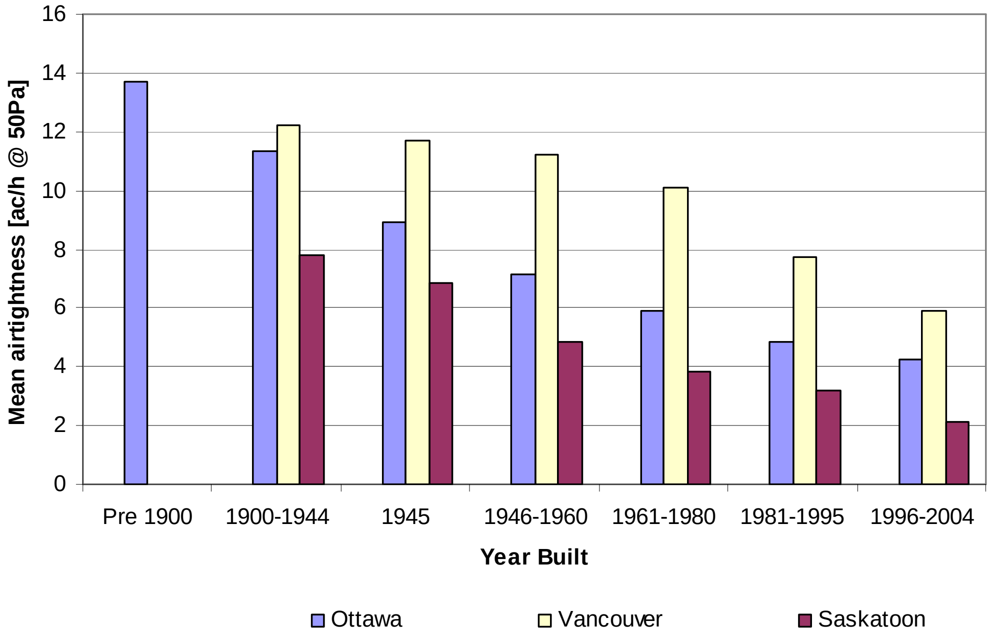

Figure 1. Air tightness in Canadian single family residential buildings (Reardon 2007).

PRODUCTS

Ventilation products used in Canada are certified by the HVI (Home Ventilating Institute) or the CSA (Canadian Standards Association). There are applicable standards for noise levels (e.g. HVI 915 or CAN/CSA-C260-M) and for the air flow (e.g. HVI 916 or CAN/CSA-C260-M). In the case of HRV units the airflow is rated in accordance with CAN/CSA-C439. The results of these tests are provided in a uniform manner for practitioners.

In the survey by Thompson et al (2009) it was reported that almost 10% of respondents used the manufacturer's manual or manufacturers training as information sources for ventilation system design/specification/installation/inspection. This would indicate that practitioners are in general not using information provided by manufacturers and are relying on other information sources (e.g. Building codes and ASHRAE).

To pass information onto home owners documentation is delivered to the owner on the furnace and hot water tank stating when it has been installed, checked and how often maintenance should be undertaken, with contact number of the manufacturer/installer. This is reinforced by utilities with regular reminders to ensure maintenance is carried out coupled with promotions for their annual maintenance service contracts for furnace, A/C and hot water tank.

Despite the existence of multiple standards there are still gaps. The National Research Council of Canada (NRC) is leading an effort to address these gaps by responding to industry’s need for comprehensive standards, for example, for HRV/ERV technology Magee et al (2012) developed an integrated test protocol complementing existing standards with tests for VOC and ozone emissions as well as particulate removal effectiveness. Sultan (2011) also developed a test protocol for portable room air cleaners covering particulate removal, noise levels, energy efficiency and by-product formation (including VOCs, ultrafine particulates, ozone and aldehydes).

DESIGN

The HRAI (Heating, Refrigeration and Air Conditioning Institute of Canada) certifies ventilation contractors. They also provide training for a range of HVAC/IAQ practitioner needs, for instance the three day course on mechanical ventilation design covers the minimum code requirements and CSA F-326 Standard "*Residential Mechanical Ventilation Requirements*" requirements as well as duct design, depressurisation testing and systems for specific HVAC options (e.g. baseboard heated houses). The training/guidance provided is tailored to the code requirements of the jurisdiction that the audience practices in. The material presented covers the minimum requirements as well as good practice and a range of commissioning, operational and maintenance issues. Certification is based on this training and achieving 75% in a written exam and is valid for five years. Arbitration/decertification procedures are in place should the homeowner, builder or building official question the quality of an installation, for more information see: http://www.hrai.ca/skilltechtraining.html.

Within the province of Québec, the Corporation des maîtres mécaniciens en tuyauterie du Québec (CMMTQ) undertakes a similar role to the HRAI.

The NBC has prescriptive flow rates (for Part 9 buildings the rates are defined in table 9.32.3.3. (2) (NRC 2011)). The code also allows the use of CSA F-326 where the ventilation rate is specified based on room types. In general the CSA F-326 approach results in greater outdoor air flow supply rates than the basic NBC method (assuming no supplemental fans are installed).

A key component of system design (and included in the NBC since 1995) is the requirement to circulate outdoor air throughout a house, i.e. natural convection/advection between rooms and induced flow from exhaust fans cannot be relied upon for mixing.

To investigate the necessity of code requirements Reardon (1997) reported completed tracer gas experiments which showed that:

- Exhaust-only ventilation approach with only local exhaust fans, with or without passive inlet vents, do not provide air distribution meeting room-by-room requirements.
- Partially distributed exhaust approach helps, but passive inlets vent very little.
- Balanced ventilation systems tend to over-ventilate lower levels as natural infiltration effects are not suppressed.
- Ventilation supply ducted to each room works reasonably well, as expected, but uniform distribution can be confounded by natural infiltration.
- Central system forced-air circulation mixes the house evenly, even with doors closed.

INSTALLATION

HRAI certifies individuals for residential ventilation installation, ventilating design and residential load calculation and duct design. Individuals who are certified by HRAI carry a wallet card bearing the certificate number and expiry date. HRAI publishes a list of certified persons, organized by city name. There are other certifications, usually provincial trade licensing requirements for working on gas, oil, electric or refrigeration-based systems. An advantage of the HRAI certification is the complaint and arbitration process. This gives some level of assurance to consumers that if they are not satisfied with the certified person's work, they can appeal to the HRAI for investigation. If the certified person is found not to have followed the appropriate guidelines, he or she will be asked to set things right and if not, certification may be withdrawn.

The HRAI certification for installation of ventilation systems is designed for Contractors, Installers and other Building Professionals currently involved with designing and installing mechanical ventilation systems for the residential sector. The three day course is based on Canadian Building Codes and the CSA F-326, and covers the installation and commissioning of all types of mechanical ventilation systems with or without heat/energy recovery, 'house as a system' principles and basic ventilation system design, including: ventilation capacity; air distribution; exhaust-type systems' balanced system; HRV and ERV systems; and interaction with other mechanical systems. The course gives an overview of several other areas including: depressurization testing; air flow measurement and system start-up.

COMMISSIONING

Practitioners certified by HRAI will understand the importance and how to commission ventilation systems, however there are no minimum building code requirements for system commissioning.

In addition to the training course described above the HRAI provides an advanced two day training course and a manual on commissioning for practitioners covering the selection of instrumentation devices, where to take measurements and how to adjust system flows to achieve the intended performance. The manual also provides worksheets to assist practitioners.

Commissioning is generally the responsibility of the installer. The Canadian Home Builders Association (www.chba.ca) provides a detailed checklist for HRV/ERV's in their Builders Manual (CHBA 2008). The checklist covers:

1. General issues, including: training/registration of the installer, code requirements (which code rather than specific clauses), location of the equipment and sealing of the ductwork.
2. Ventilator installation, including: noise transmission, control, air flow measurement
3. Cold side ductwork, including: insulation, vapour barrier, length, sealing, location of terminals (on outside of house).
4. Warm side ductwork, including: supply/return requirements for each room, system design, duct location (generally inside the heated envelope).
5. Warm side exhaust ducts (e.g. bathroom exhaust fans), including: location of exhausts, ducting filtration and type.
6. Warm side supply ducts, including: direct connection to a forced air system, dedicated ventilation distribution.
7. Verification of operation, including: measurement and adjustment of flows, balancing total supply and exhaust, verification of control operation.

MAINTENANCE

Maintenance of ventilation systems is primarily the responsibility of the homeowner. The Canada Mortgage and Housing Corporation (a federal government agency, www.cmhc.ca) provides multiple information packs on maintaining and renovating homes as well as specific literature on 'the house as a system' and specific types and vintages of homes. Specific guidance on ventilation is also provided (CMHC 2013). In general Canadian homes are well maintained, only 7.5% of the built stock required 'major repairs' and 66% required 'regular

maintenance only' according to the CMHC (2006). This may be due to the relatively high ownership rate of 70% (CHMC 2006).
Many home owners will use service companies to carry out HVAC maintenance on an annual basis (the utilities and many contractors offer this service). These companies will be certified by HRAI with individual technicians certified for specific trades (gas fitter, electrician etc).

Despite the availability of information (e.g. CMHC 2010) and service companies available to do the work, anecdotal information is that many home owners do not carry out even the most basic of maintenance, for example changing filters. This is compounded in some cases by sub-optimal installation (unit out of reach, interference with other equipment). Fugler (2010) summarised CMHC's findings from a 1996 survey of HRV operation in 60 homes:

- 42% showed dirty cores
- 17% had blocked intakes and pre-filters (see Figure 2)
- 55% had unbalanced systems
- 60% had substandard ventilation (not meeting code)
- 55% of homeowners with furnace circulation connections did not know that they had to run the furnace fan in order for the HRV system to be effective.

INSPECTIONS

Home inspectors are generally used by prospective buyers of a home and require knowledge of the types of ventilation systems, the principles of ventilation and should be able to identify the various types of ventilation systems (CAHPI 2001). In addition to these high level competencies they should also be able to identify the materials and components used in the ventilation system. They should further be in a position to observe the operation of the ventilation system, having knowledge of the proper/improper operation and how control devices work.

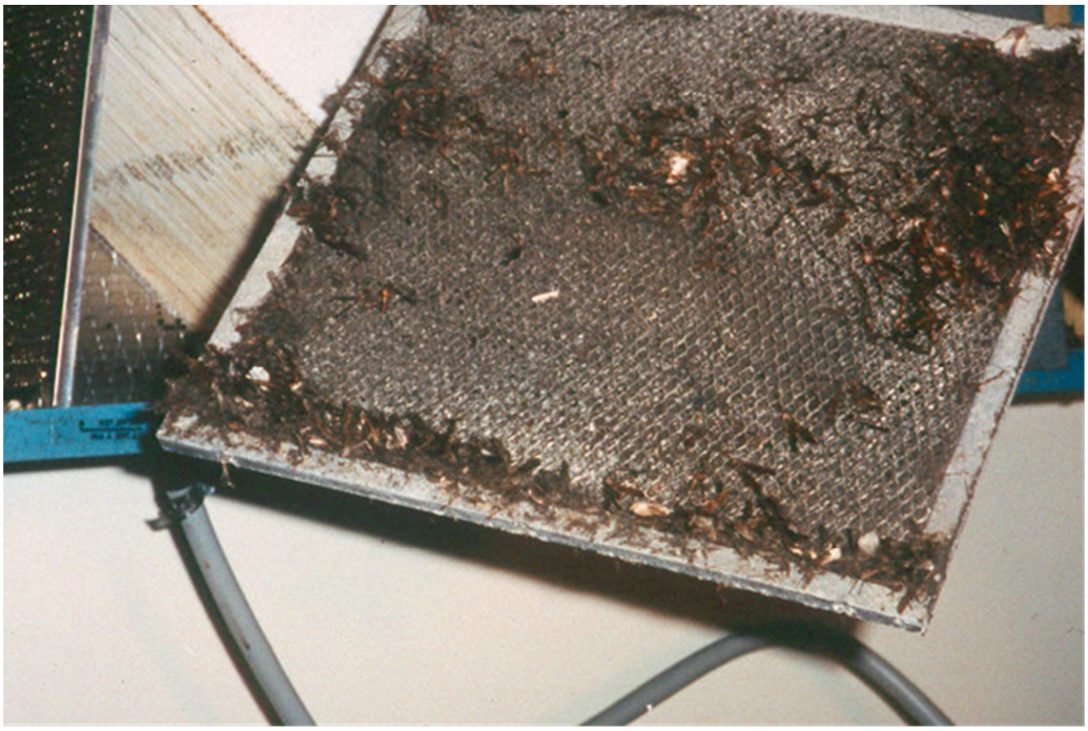

Figure 2. Filter from CMHC study (Fugler 2010).

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

The NBC has recently been updated to include energy requirements. The 2011 edition introduces a calculation procedure where the proposed building is compared to a code compliant building (there is also a prescriptive path). With respect to ventilation the rate is determined from the prescriptive table in part 9 of the code (table 9.31.3.3) and assumes operation of the system for 8 hours per day. The operation and sizing has to be the same for both the proposed and reference building.

Table 2: 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.

Topic	Major causes of quality problems	Existing quality schemes or incentives
Product	Lack of comprehensive certification testing.	Gaps in product evaluation testing are being addressed.
Design	Ineffective particle filtration in most cases	Flow rates clearly described in building codes and a national standard. Existing requirements have been in place for over two decades.
Installation	Limited space and installation style options for retrofit installation	Certification programs for installers in place.
Commissioning	Guidelines and documentation could be improved	Certification programs for installers in place.
Maintenance	Routine maintenance requirements for HRV/ERV systems poorly understood or performed	Information available but uptake was reported as low in 1996 survey.
Operation	Incomplete documentation of individual ventilation components and 'house as a system' operation techniques. Lack of field data on how users operate ventilation systems.	

ADDITIONAL INFORMATION NOT COVERED IN PREVIOUS SECTIONS

In general there is a lack of current information on how occupants use their ventilation systems and what maintenance they perform. Most surveys are not comprehensive and do not fully address key aspects of either building science and/or air quality/health impact; the one exception was that reported by Aubin 2011. Coordinated action would benefit all actors in the residential market, allowing an informed basis for future products, code changes and homeowner education.

CONCLUSION

- Residential mechanical ventilation has been required by code since the 1980's, resulting in familiarity of the systems by contractors and home owners.
- 25 % of single family residential homes have been built since 1990, when the last major chance to ventilation requirement was made to the model national building code.
- Building codes are becoming more detailed and comprehensive in addressing important aspects of residential ventilation in order to provide effective and sustainable solutions for the provision of comfortable, healthy indoor environments.
- Further study, including comprehensive field investigations and engineering design evaluations using full-scale test facilities are required to advance progress in these critical areas

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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 CO_2 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).

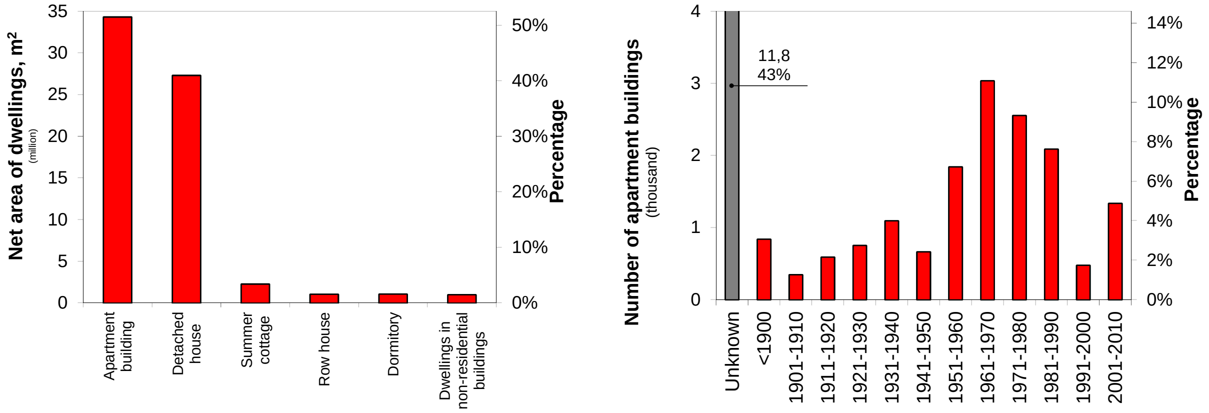

Figure 1: Distribution of dwellings in subdivisions according to net area (left) and year of construction (right).

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.

Type of ventilation system	Type of dwelling and construction period									
	Detached houses					Apartment buildings				
	<1920	1921-1945	1946-1970	1971-1990	1991-2010	<1920	1921-1945	1946-1970	1971-1990	1991-2010
No ventilation (window airing, no special stack for ventilation)	■	■	■			■				
Natural supply and exhaust (passive stack ventilation)	■	■	■	■			■	■	■	
Natural supply and mechanical exhaust				■	■				■	■
Mechanical supply and exhaust with heat recovery					■					■

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·m^2)) only in a few apartments. Even average general airflow (0.3 l/(s·m^2)) was below the indoor climate category III target value (>0.35 l/(s·m^2)).

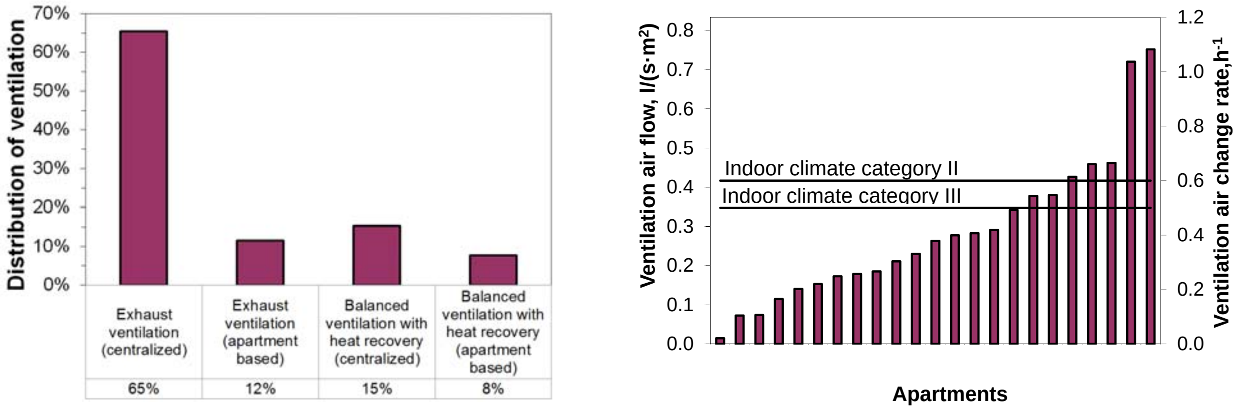

Figure 3: Distribution of dwellings in subdivisions according to distribution of ventilation (left) and ventilation air flow (right).

Indoor CO_2 measurements showed high levels of CO_2 (see Figure 4 left) indicating bad indoor air quality. Based on measurements of indoor CO_2 levels and estimated CO_2 (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.

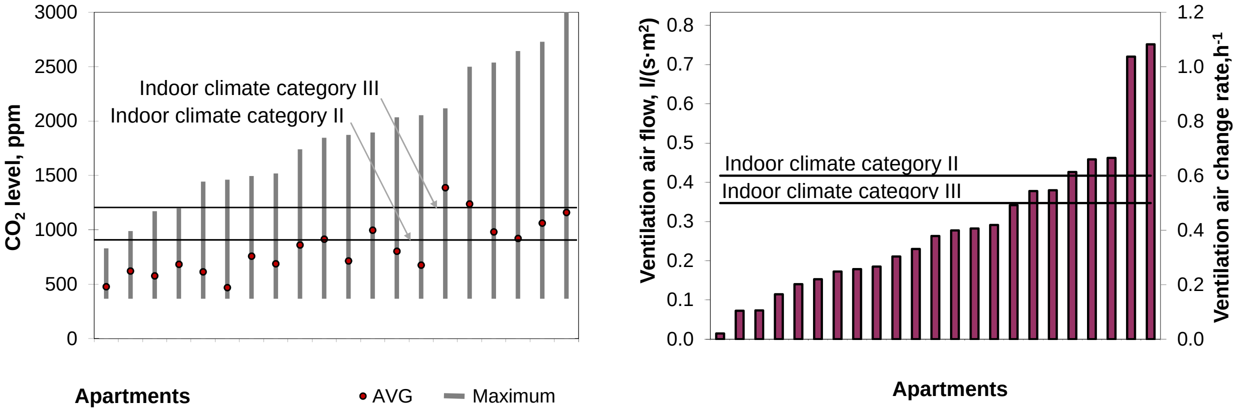

Figure 4: Distribution of dwellings in subdivisions according to net area (left) and year of construction (right).

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).

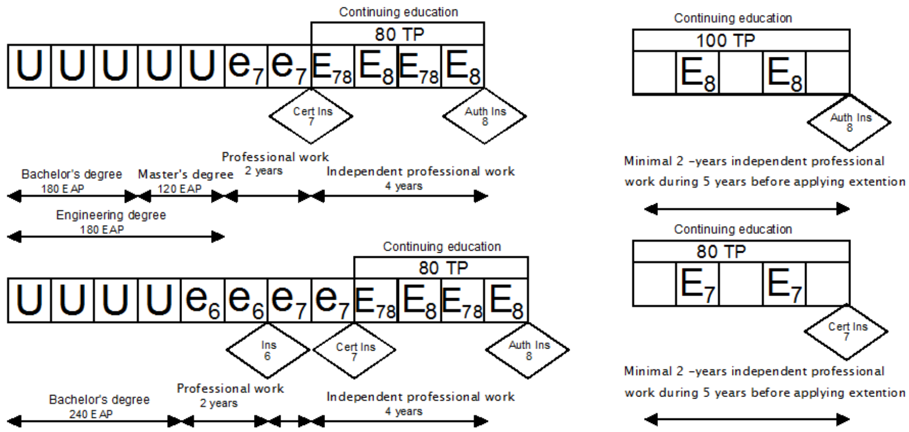

Figure 5 Scheme for applying first-time professional levels of HVAC engineers (left) and applying the extension (right).

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 m^3/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 CO_2 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 takes the measures after the installation.

		Supply air		Exhaust air		
Time period	Standard	Living room	Bedroom	Kitchen	Bathroom	WC
- 1991	СНиП II-Л.1-71 СНиП 2.08.01-85	1 h^{-1} (earlier) 0.8 l/(s·m^2)	1 h^{-1} (earlier) 0.8 l/(s·m^2)	20 l/s (75 m^3/h)	7 l/s (25 m^3/h)	7 l/s (25 m^3/h)
1991 – 2000 (still used)	Finnish NBC-D2	0,5 l/s/m^2	4.0 l/(s·pers) or 0,7 l/s/m^2	20 l/s (72 m^3/h)	15 l/s (54 m^3/h)	10 l/s (54 m^3/h)
2000-2007 (still used)	EPN18.3.2/ EVS 845-2:2004/	0,5 l/(s*m^2)	0,7 l/(s·m^2)	20 l/s	15 l/s	10 l/s
2007-	EVS-EN 15251: 2007	IC category II 7 l/(s·pers.) 1.0 l/(s*m^2) III: 4 l/(s·pers) 0.6 l/(s*m^2)	IC category II: 7 l/(s·pers.) 1.0 l/(s·m^2) III: 4 l/(s·pers.) 0.6 l/(s·m^2)	IC category II: 20 l/s III: 14 l/s	IC category II: 15 l/s III: 10 l/s	IC category II: 10 l/s III: 7 l/s
2006-	CEN/TR 14788		3…5 l/(s·pers.)	1.5…7.5 l/(s·pers.)	approx. 15 l/s	approx. 10 l/s

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

Indoor climate category	Expected percentage dissatisfied, %	CO_2 concentration at outdoor air level 350, ppm	Indoor air CO_2 concentration, ppm
I (A)	15	460	810
II (B)	20	660	1010
III (C)	30	1190	1540

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 P1≤0,7 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.

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

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.

ACKNOWLEDGEMENTS

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

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ABSTRACT

Air exchange rate and indoor air quality demands are well defined for commercial and residential buildings in the national building code. The energy efficiency demands are easiest to fulfil with the mechanical ventilation systems and therefore, the mechanical supply and exhaust systems are the most popular ventilation systems in the new single family houses and terraced apartments. For apartment and single family houses the systems are smaller but they need to meet the same quality criteria than those designed for large buildings. The general principles for design and installation follow those. If all the instructions are taken account, sufficient amount of fresh air and also contaminants of indoor origin will be diluted enough that high indoor air quality is maintained. In practice many malfunction exists: ventilation is too noisy or the ventilation is not used as high power as it should. This may be due to design with too small ductwork and insufficient sound attenuation, or the good design features are neglected during the installation. The installation is not demanded to do by professionals that may lead to some installation mistakes or the balancing of the systems is not well performed. The maintenance is usually done by the building owner who does not have proper education for that work. Voluntary classification of indoor environment gives external instruction to design, install and maintain the high indoor air quality.

KEYWORDS

Residential building, ventilation criteria, regulation, guideline, air exchange rate, cleanliness of ventilation system

INTRODUCTION

In Finland, a general guideline for planning building heating system was given first time in 1917 (Normaalimääräykset lämmityslaitoksia suunniteltaessa, 1917) and a guideline for planning heating and ventilation systems in 1955(Lämmitys- ja ilmanvaihtolaitteiden suunnittelun normaaliohjeet, 1995). The first specific regulations for planning buildings ventilation was published in the national building code in 1975 (D2, 1976) and revised version regulations and guidelines in 1978(D2, 1978). General principles and outdoor, supply and exhaust air flow rates for rooms for different purposes were stated in these guidelines. The guidelines were made to design ventilation systems to maintain good indoor air quality in the residences and also other buildings. The third edition of the guideline was published in 1987(D2, 1987), which included also regulations for indoor air quality factors such sulphur and nitrogen dioxides, carbon monoxide and particles, The fourth edition was published in 2002 (D2, 2003) inn which heat recovery and energy performance were also included. The building code has directly affected to the ventilation demands and indoor air quality in the Finnish buildings. The latest version was published in 2011 (D2 2012), which takes account new energy regulations.

Until these years the natural ventilation is the dominating systems in block of flats. These systems in are designed for common exhaust ducts or the separated ducts for each of the apartments. The same is for detached houses, but the development towards mechanical supply and exhaust systems is faster than that in block of flats. Since 2003, ventilation systems in new single family houses are mainly mechanical supply and exhaust systems with heat recovery.

The total number of Finnish residences is about 2.8 million (Figure 1)[8]. Apartments in block of flats and single family houses are the most popular way of living. The amount of terraced houses has increased during the last two decades. The increase of total number of residences and also increase of the renovation in the existing buildings creates the markets in building construction and also in installation of the ventilation systems.

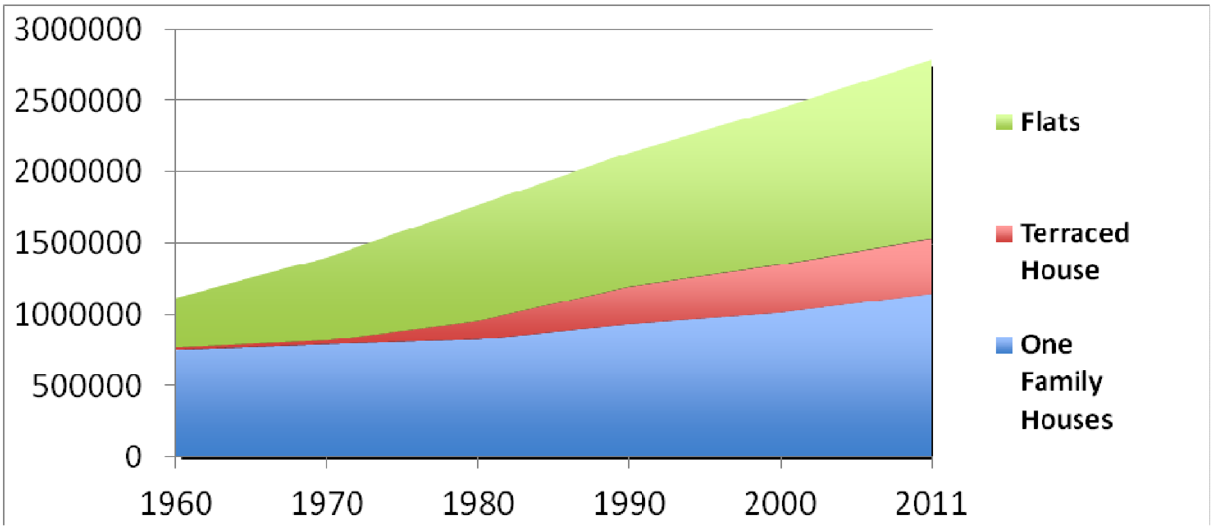

Figure 1. The number of Finnish residences and percentage of the different types of the residences [8].

RESIDENTIAL VENTILATION MARKET

The indoor air quality demands combined to the energy saving demands has driven towards mechanical supply and exhaust ventilation with heat recovery. In figure 2 are shown the number and percentage of natural, mechanical exhaust and mechanical supply and exhaust ventilation systems in the Finnish building stock. The natural ventilation is still the most common and it is derived from the large percentage of the flats. The situation is changing, because the new buildings and renovation of the older buildings will increase the number of mechanical systems. The demands for the energy efficiency will also drive the development towards more mechanical ventilations systems.

The building code states the high demands for the ventilation and energy efficiency. This means that designers need to choose mechanical ventilation system with heat recovery [7]. One demand is that the efficiency of ventilation should be possible to adjust during more dense occupancy and loading the residence. In mechanical systems the power of the fan shall be adjustable. In buildings equipped with natural ventilation the increase in efficiency is done by opening the windows.

The design of the ventilation systems is checked by the authorities who give the permission to start the building process [12] (National building code). The designer needs to have professional training level C, which is the lowest demand for the designers (A2) [12].

In practice, the air exchange rate (ACH) is typically lower than demanded in the building code. The ACH determined from measurement of exhaust air flows is show in figure 3. During the measurement the fan power regulator was set to the position that occupants used during their normal living. The median of ACH was 0.38 1/h in houses equipped with mechanical supply and exhaust ventilation and 0.40 1/h in buildings equipped with mechanical exhaust ventilation. [13] (Vinha et al 2005). The occupants prefer to use the lowest power in most of the houses (55%) and according to the interview of the occupant the noise level was the main reason to keep the efficiency of ventilation on the minimum power. It can be concluded that the design the air flow rates is not the problem, but the problem is insufficient sound attenuation in the systems. So the design of noise control with sufficient sound attenuation and bigger dimensions of air duct is a problem in many of the residential ventilation systems.

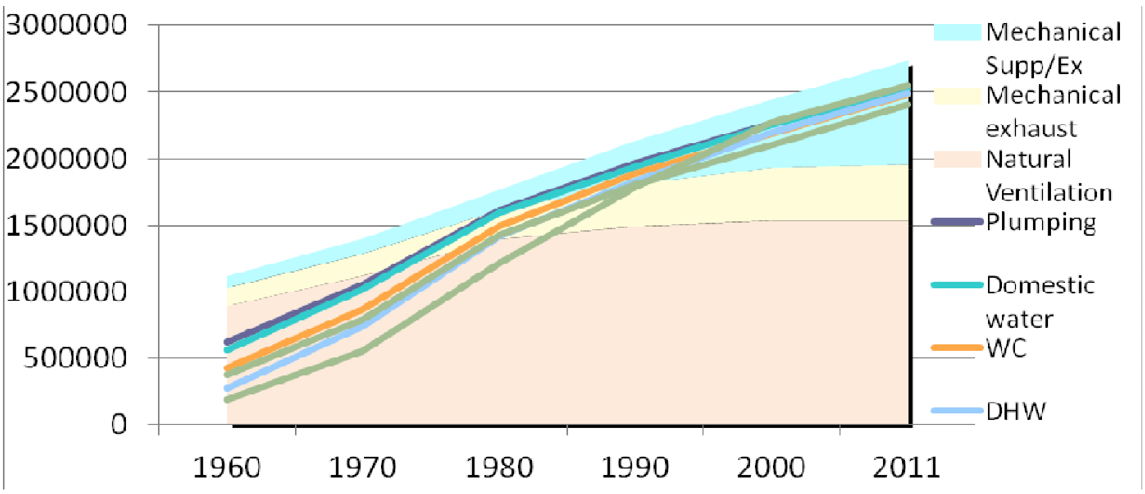

Figure 2. Number of different techniques applied in the Finnish building stock [9,10].

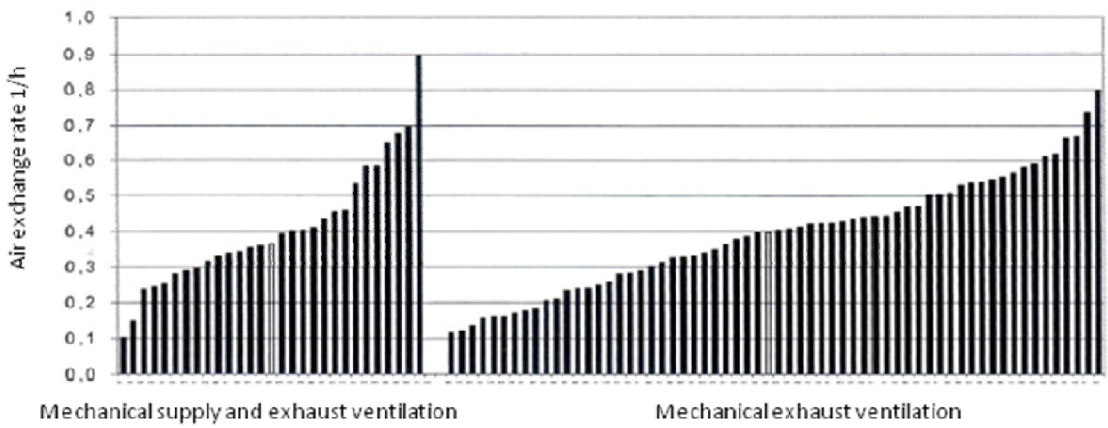

Figure 3. Air exchange rate in wooden single family houses equipped with mechanical supply and exhaust ventilation and with mechanical exhaust ventilation [13] (Vinha et al 2005).

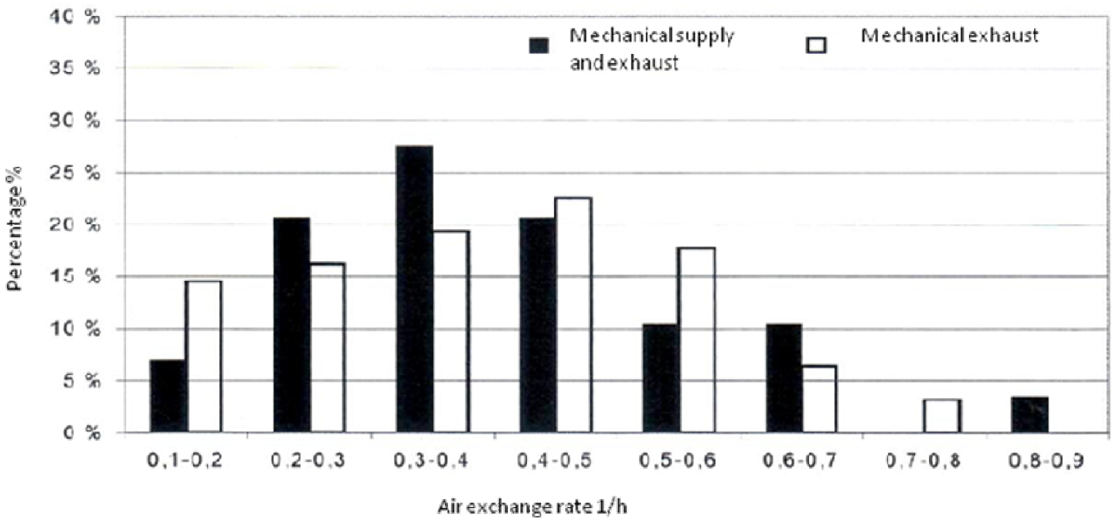

Figure 4. Distribution of air exchange rates in single family houses (N=92) (Vinha et al 2005). [13].

In the houses equipped with mechanical supply and exhaust ventilation systems the ACH was lower than houses with mechanical exhaust ventilation system. The difference was not statistically significant.

PRODUCTS

The ventilation systems in residences are designed with the principle that the simple and straightforward is the best. In the block of flats the exhaust ventilation system is equipped with exhaust fan located in the roof and duct work downwards to near the kitchen and bathrooms. The mechanical supply and exhaust ventilation system servicing for a single residence, contains usually a compact air handling unit with supply and exhaust fans, filters and heater for supply air. Recuperative heat exchanger is the most often used. The duct work dimensions are varied normally between 100 and 160 mm. The duct work and the other components are the same than for the systems built in offices and commercial buildings. The components are cleanliness classified and labelled with M1 label. [14]

The Classification of indoor climate defines the design features if building owner defines the cleanliness and installation to do according to the classification. The following criteria are set for cleanliness.

- Oil residues:
  - 50 mg/m^2 for products manufactured without lubrication
  - 300 mg/m^2 for products that need lubrication in manufacture
- Dustiness
  - > 0,5 g/m^2 delivered new components
  - > 0,7 g/m^2 for installed ventilation systems
- The products should not release odour or fibres
- Testing once with every 6 years, new application every 3 years

VTT Technical Research Centre of Finland is responsible for all type approval activities from the 1st of January 2009. The authority in the area, Ministry of the Environment has ended its type approval activities. Type approval will continue as a voluntary procedure.

Figure 5. According to the Finnish Classification for indoor environment the ducts and components need to be protected during transportation and storage.

Type approval can be applied for from VTT Expert Services Ltd for the following products:

- Air handing units
- Air filters
- Air ducts and sections of ducting
- Air conditioning terminal devices, sound dampers and outdoor air vents
- Air flow measuring devices

VTT also provides energy efficiency tests and certificates for annual heat recovery and specific fan power SFP of ventilation systems.

DESIGN

Design of ventilation systems is authorised to the persons who has a degree in HVAC engineering in which the design plays an important role in the degree. For residential buildings the demands for the designer education or experience is classified to C level, which is the lowest class. It means that the designer should be professional, but the experience needed is not so critical (A2). These dedicated training schemes cover the persons and in the companies who are doing the design work need to have persons who have the demanded classification for designer (A2). C level demands accept test, which is valid for a specific period.

Finnish association of HVAC societies provides training schemes for ventilation professionals to become qualified supervisor of installations or designs of ventilation systems.

Table 1. Design criteria for indoor air quality parameters (D2, 2012)

Contaminant	unit	Design criteria (maximum)
ammonium, amines	$\mu g/m^3$	20
asbest fibres	$fiber/cm^3$	0
formaldehyde	$\mu g/m^3$	50
carbon monoxide	mg/m^3	8
carbon dioxide		1200
particles PM_{10}	$\mu g/m^3$	50
radon	Bq/m^3	200 (annual average)
styrene	$\mu g/m^3$	1

The general design demands and guidelines are described in the national building code [7] and also in Finnish Classification of Indoor Environment. The national building code defines design temperature ranges, air flow rates and ventilation criteria for different spaces and also the IAQ criteria for some parameters presented in the Table 1 [7]. To obtain the criteria for ammonia, formaldehyde and styrene needs take account the emissions from the materials. To control radon gas emission from soil needs to air tightness of building envelope or special ventilation for radon gas..

INSTALLATION

There are education programs for ventilation installation. The degree may be focused on the installation of ventilation systems and the plumber may be as second specialization or vice versa. There are no educational demands for the installation of ventilation systems specially for private houses. In practice, in most of the houses the ventilation systems are installed by professional company. Some of the single family owners are installing the systems by themselves, if they have experience enough from installation work.

In most of Finnish ventilation system installations, attention is paid to cleanliness of the systems when they are taken in use. This means that clean and classified products are used and the system is installed in time when no dusty works are going on the building construction site. To obtain clean system, for example, the cutting of ducts to desired length is recommended to do with special cutting tools, so that metal powder or other debris will not be driven inside the ducts during the work (Figure 6ab).

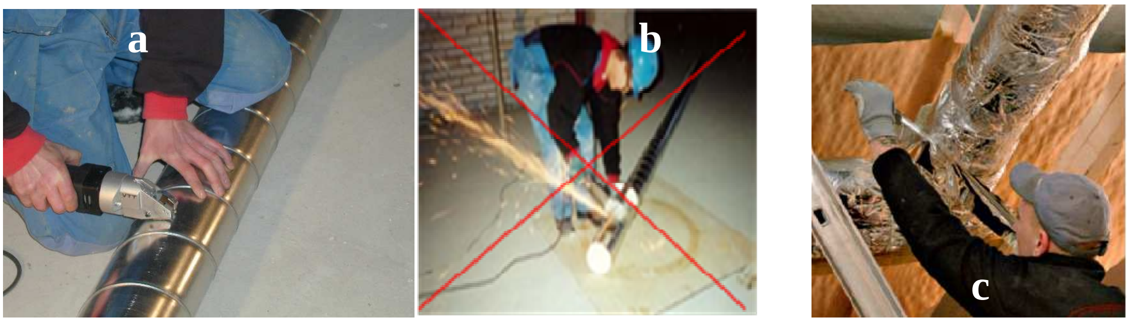

Figure 6. Electric scissors by which the duct can cut without dust inside the duct work.

A part of the ductwork is usually designed to place in a cold attics which promotes water condensation. This promotes risks for water condensation in to the exhaust air ducts during winter. A good thermal insulation is needed to avoid the problem (Figure 6c).

TalotekniikaRYL 2002 (2003) describes a generally accepted standards for good construction practice. The document gives also general demands for installation work of HVAC systems. The guidelines presents materials and methods to achieve design end results. The guidance and instructions for high quality installation manners are presented in general installation guideline for technical systems in buildings. In addition, introduction to use and instructions for use and maintenance are demanded to deliver. [Talotekniikka RYL 2003].

COMMISSIONING

Commissioning of ventilation system in residential building is a part of the commissioning process which is mainly focused on building structures, dimensions and other technical things. E.g. the fire safety of building is checked in the commissioning process which is instructed in the building code (A1). The ventilation system needs to be tested and balanced before commissioning.

During the ventilation system commissioning the air flow rates are checked from the table in measurement notes done after the adjusting the air flows and balancing the system. The values are compared to the design values and only 20% differences are allowed for the system air flows.

The commissioning is mandatory and it is part of the inspection process for building structures included in the permission process. The authorities will do the commissioning [7, 8].

MAINTENANCE

There are no official regulations for residential ventilation maintenance actions in Finland. General fire safety demands are given [9], but they are not checked by authorities as a part of maintenance program. In single family houses and terraced houses the maintenance of the building is usually done by the building owner who does not have professional education in that field. Usually, the sufficient instructions are following the building ownership (see Installation chapter). These instructions includes how to use ventilation system in daily life, how to adjust the air flows, how to replace supply and exhaust air filters, clean the kitchen extracts filters, how to clean the air handling unit (Figure 7). The filters should be changes once a year. Maintenance work should be recorded on the maintenance manual.

Figure 7. Cleaning instructions for heat recovery coil and kitchen extract filter.

Maintenance program of a building includes also the checking of performance ventilation system and its cleanliness. However, this kind of program has not been applied in most of the buildings. According to guideline given by the Ministry of Interior affairs the ventilation system shall be clean that it will not support fire in the system. The inspection of the cleanliness of ventilation system in residential building should be done once in ten year. According to air duct cleaners association (Finnish Chimneys Sweeping association) less than 50% of the single family or terraced houses obeys this rule. Some of the owners order the duct cleaning service regularly, but there are houses that do not follow this regulation. According to the cleaners association the air ducts are checked in about 50% of the buildings.

INSPECTIONS

Inspections of performance and cleanliness of ventilation systems are included in the professional maintenance. However, in the residential buildings the maintenance of ventilation systems in not done by professional personnel, that is especially true in the single family houses and terraced houses. In block flats, the maintenance is usually done by a professional service and maintenance companies which have hired educated service personnel. This does not guarantee the time which is allocated for maintenance of ventilation systems.

INFLUENCE OF THE QUALITY OF VENTILATION SYSTEMS ON THE BUILDING ENERGY PERFORMANCE ASSESSMENT-CREDITS AND PENALTIES

The energy efficiency of buildings and performance of ventilation systems is demanded in the national building code (D3). In practice, energy efficiency is calculated for determination of energy category. The balancing of the ventilation system is important which affects the air change rate and also moisture transfer trough the building structures. In residential buildings, there are no regular checks of the energy performance of the systems.

Table 2: 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.

Topic	**Major causes of quality problems**	**Existing quality schemes or incentives**
Product	Classified products are ok	Classification of HVAC products
Design	Sound attenuation, dimensions	More attention to noise control
Installation	Cleanliness, thermal insulation	Systematic use P1installation instructions, better control
Commissioning	As a part of building commissioning	Integration to building commissioning
Maintenance	Change of filters; cleaning Air flow rates	Maintenance instructions, rebalancing when cleaned
Inspection	Too low ventilation rate	Increase of knowledge
Operation	Too low ventilation rate	Increase of knowledge

CONCLUSION

In many residential buildings the air exchange rate does not meet the criteria set for ventilation. The problems are most often in use, because users like to minimize the energy consumption and also to reduce noise. In addition to this maintenance of the ventilation system has often neglected by the users/owners of the houses. The noise control of the ventilation systems in residential buildings is often neglected in design or during installation. The commissioning process need to develop to inspect also the performance of the ventilation systems so that the features during the normal use will be also checked. The cleanliness of the ventilation system is inspected and duct work cleaned in half of the systems in residential buildings. This need to include in the maintenance program.

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

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ABSTRACT
This paper provides an overview of the various initiatives that are taken in France in order to secure the quality of installed ventilation systems in residential buildings.

KEYWORDS
Ventilation, regulation, certification, technical rules, France

RESIDENTIAL VENTILATION MARKET

Since 1982, buildings in France are mostly equipped with centralised mechanical ventilation systems. The dwellings built before 1980 were usually equipped with natural ventilation systems (either room by room or with centralised exhaust ducts). There is still more than 20 % of residential building without ventilation system. Table 1 details the type of ventilation systems installed in the stock of existing houses or apartment buildings in 2004.
Nowadays, nearly 95 % of new residential buildings are equipped with centralised mechanical exhaust demand control ventilation systems based on humidity sensor (Savin, 2009).

Ventilation system	Apartment buildings	Single family houses
No system	9 %	14 %
Natural room by room	34%	36%
Natural with ducts in technical rooms(1) and air inlets in other rooms	16%	22%
Fan assisted natural (hybrid)	1%	
Decentralised mechanical exhaust	0%	1%
Centralised mechanical exhaust using existing collective natural ducts (renovation) (2)	13%	
Centralised mechanical exhaust with self adjusting airflow(2)	22%	23%
Centralised mechanical exhaust with demand control based on humidity(2)	5%	5%
Centralised mechanical exhaust and supply (balanced)	0%	1%
Ventilation strategy		
No ventilation	9 %	14 %
Decentralised ventilation (room by room)	34%	36%
Centralised ventilation (mechanical or natural)	57%	50%
Nb of dwelling (at the study time - 2004)	13 066 266	17 333 069

(1) in France "technical room" means room with major sources of humidity like kitchen, bathroom, toilets …
(2) mechanical exhaust ventilation system implies outlets linked to an exhaust fan in technical rooms and natural air inlets in bed rooms and living rooms.

Table 1 : Estimated distribution of ventilation systems for residential buildings (air.h, 2007)

Also since a few years the installation of balanced ventilation systems with heat recovery is growing in new individual dwellings: 10% of the 20,000 houses with the low energy label BBC-Effinergie were equipped with balanced ventilation systems (Effinergie, 2013). The high proportion of residential buildings equipped with a ventilation system has been achieved thanks to the French regulation (Bylaw of 24th of March 1982, modified in 1983), which requires that all new dwellings have a continuous general ventilation system, ensuring minimum extract airflow rates in technical rooms (kitchen, bathroom, toilets). This ventilation system shall not be stopped.

Demand control ventilation is possible but shall always fulfill a minimum extract air flow rate requirement. In order to verify that the DCV system will provide satisfying indoor air quality, a French Technical Assessment (Atec, delivered by CSTB) is required to put the product on the market. For other product, there is no control required.

The French regulation also includes requirements that limit the noise of ventilation systems and the noise that they transmit (from outside or from one dwelling to another, Bylaw of 30th of June 1999).

In 2009, the OQAI published a study which concludes that nearly 60 % of ventilation installations do not comply with the ventilation regulation (Lucas, 2009). In 2012, CETE de Lyon has analysed 373 compliance check reports, made by French building ministry services. On 1287 dwellings covered by those reports, 47% did not comply with the ventilation regulation (68% for single family houses and 44% for dwellings in apartment buildings). The detailed results of this study, focused on the ventilation aspect, are presented by Jobert (2013).

PRODUCTS

Ventilation products for single dwellings can join two French voluntary certification programs on ventilation systems (covering air inlets, air outlets, ventilation units and whole ventilation systems):

- "NF VMC" for self adjusting exhaust ventilation systems and balanced ventilation systems,
- "CSTBat" for demand control ventilation systems.

Those two certification programs are based on minimum requirements on air flows, electric power consumption, acoustics, air filtration (for balanced systems), and quality of manufacturing. Certification is delivered by CERTITA after initial tests of the products. Regular control tests are made on product from production.

Usually, certification programs are based of performance of "new" products. In order to ensure the ventilation quality after installation, for single dwellings:

- NF VMC requires for balanced ventilation units that air flow rate are ensured even if the filter is dirty and an alarm to detect when filters have to be replace,
- For demand control ventilation, Technical Assessment requires insulation on exhaust ductwork to limit water condensation.

For some apartment buildings, the European Eurovent Certification program, covering air handling units, heat exchangers, air filters, fan coil units, is also recognized by designers and for the energy performance of building regulation calculations.

Characteristics of product that are delivered to installers, designers or final users, are based on French, European or International standards as far as possible. Some specifics characteristics are required by national regulations:

- French energy performance of building regulation RT2012: for example, average electric power consumption
- Ventilation regulation of March 1982: for example, exhaust air volume flows or declaration of intended use based of the dwelling configuration (number of rooms)
- French Technical Assessment: for example, DCV ventilation system configuration for each type of dwelling (assembly of air inlets, air outlets and fan)

There exist also a news voluntary agreement for manufacturers based on Uniclima guidelines that defines the rules to announce the performance of different products (based on standards and regulations). Manufacturers following these guidelines can put a logo (Figure 1) on their documents to help designers and installers to compare characteristics of products.

AFFICHAGE DES PERFORMANCES
Les produits repérés par ce logo respectent les recommandations d'affichage des performances définies par Uniclima.

Figure 1 : Logo of voluntary agreement – Uniclima guidelines for performance display

During the last years, the manufacturers developed new products to improve the quality of installations:
- New types of rigid and semi rigid ducts to replace the generally used flexible ducts for individual centralised ventilation system, in order to limit the pressure drop
- Access trap for ductwork cleaning in apartment buildings
- Balanced ventilation units with alarm to detect if filters should be replaced
- Ducts and fittings with higher air tightness to limit air leakage

Typical French exhaust mechanical ventilation systems are designed to ensure the needs of fresh air without any technical operation from the users who should only clean the inlet and the outlet every month. The two main types of systems are:
- Self adjusting airflows ventilation systems, called “autoréglable”, designed to adjust by themselves the volume air flow in single dwelling: assuming a minimum pressure drop, the outlet has a mobile part which ensures flow control. Therefore there’s no need to adjust airflow after each installation. The ventilation unit is designed to give this minimum pressure regarding a typical ductwork. There are minimum requirements for the NF VMC certification.
- Demand control ventilation units based on humidity, called “hygroréglable”, designed with the control directly by the air outlet (automatic change of flow section due to humidity) without any electric or electronic system. This implies that maintenance is not needed for this control.

Ventilation system manufacturers propose help for design and good installation by:
- Developing software to design installation adapted to their products characteristics
- Providing installers training programs
- In some cases, providing commissioning of the installation.

Ventilation system manufacturers in France participate, directly or not, on studies in order to improve quality of installations. For example, the air.h association, has operated with technical centers, building constructors and ventilation system manufacturers, the “Performance de la ventilation” project (air.h 2009) which included fields campaigns, mainly on air volume flow to check the compliance to the regulation and the writing of a quality guide to improve building and ductwork air tightness (CETE de Lyon 2009).

Ductwork manufacturers propose now to installers measurement facilities in order to test air tightness of the ductwork. To improve the quality of installations, French manufacturers contributed technical guide published by CETIAT (Guedel, 2012) that defines the main rules for ductwork quality. Another technical guide published by CETIAT is available (Caré, 2012) to choose relevant on site air flow measurement methods.

To improve the quality of ventilation installations, collective measures are:

- Uniclima technical guide and training scheme about the main installation rules of residential ventilation systems
- Creation of new specifics ventilation qualifications for installers

Therefore, Uniclima contributes to the installation recommendations written by COSTIC in the national program called RAGE (2013).

DESIGN

Residential ventilation system designers can follow engineer or technical manager education, focused on energy or HVAC programs. There's no specific ventilation program. Example of institutes providing those programs:

- IUT (technicians) « *Génie Climatique* » or « *Génie thermique et énergie* »
- INSA (engineers) in Strasbourg & Lyon « *Génie climatique et énergétique* » or « *Génie énergétique et environnement* »

Some dedicated training sessions are proposed for designers in CETIAT, COSTIC or CSTB for example.

There is no specific qualification for designers in ventilation but general qualification is provided by OPQIBI and is recognized by public procurement code. Also energy consultants could be certified by AFNOR (*NF Etudes thermiques*). Those qualifications cover companies and persons and are based on administrative requirements to check the quality of the companies and the competence of the employees. To reach the certification level, audits are operated into the companies.

Usually designers know regulations, technical rules and recommendations that apply to ventilation systems. Some are mandatory: Energy Performance of Building (RT 2012 and RT existant), Acoustic, Technical Assessments,etc. Others are just recommendations: NF DTU, CSTB guide and acoustical solutions.

The French ventilation regulation allows all types of systems to be installed provided that they can ensure the minimum exhaust air flows rates required, whereas it is by natural, hybrid or mechanical ventilation.

French Unified Technical Rules (NF DTU 68.1 and 68.2) define guidelines to design, install and maintain single and collective mechanical ventilation systems. Those technical rules are under revision and should become NF DTU 68.3 in a nearly future. If the ventilation system is also used to extract combustion products from heating appliance, specifics rules are defined in DTU.
For demand control ventilation systems, design guidelines are described in Technical Assessment of the concerned system. For fan assisted natural ventilation systems, designers can rely on a guide provided by AVEMS (2010).

For existing buildings, there is no legal obligation to install a ventilation system but the energy performance of building regulation requires, if a ventilation system is implemented, to have a fan electric power consumption under 0,25 W/(m^3/h) and 0,4 W/(m^3/h) for balanced ventilation units with minimum M5 filter. Also, the French regulation for existing building requires to install air inlets or ventilation system when the windows are replaced in order not to decrease the indoor air quality (IAQ).

The acoustics of building regulation (1999) limits the acoustic level to 35 dB(A) into the dwelling. In order to help designers to comply with this requirement, CSTB provides typical technical solutions.

For the moment, the priority has been given to the energy performance but IAQ is more and more integrated to buildings design. For example, IAQ becomes a major concern in new buildings because of requirement on building air tightness: the HVAC engineers association AICVF is aware of this problem and has already written guides on this topic (AICVF, 1992). HQE association, which delivers high environmental quality label for buildings, describes how to reach a good IAQ in existing and new buildings. Some designers are members of the association and promote this label.

INSTALLATION

A professional dedicated qualification program has been developed for installers by UECF (French association of HVAC installers). There is also a voluntary education scheme named "*Les compagnons du Devoir*". Training schemes for installers are proposed by CETIAT, COSTIC, CSTB, AFPA and some other organisations that can propose a dedicated formation module named FEEBAT.

QUALIBAT and QUALIFELEC are two qualifications for ventilation system installer companies. They are delivered after an administrative exam with possibility of audits in companies and on installations. Theses qualifications do not affect the energy performance calculation and they don't allow receiving subsidies, which are limited to product performance requirements only.

Installation standard and guidelines are very often coupled with design. Therefore installers can rely on DTU 68.1 and 68.2 (68.3 in the future), and Technical Assessment. Moreover specific guides and recommendations are available: Uniclima technical guideline (1997), rules of reception from COSTIC, RAGE recommendations.

Installers should provide documentation to the end user, but generally users are not well informed of the product installed. At the moment, there is a voluntary building quality label «Label Qualitel» which proposes a guide called GISELE with the description of HVAC systems installed into the building.

Ventilation and IAQ is today not a priority regarding energy issues. Some installers are aware of the role they can play but only a few hundred of companies are qualified for the moment. As a comparison, in the renewable energy field, they are more than ten thousands qualified.

COMMISSIONING

Generally, for residential buildings there is no test of the ventilation system during commissioning, but it is required when ventilation system is used also to extract combustion products from heating appliances.

Technical rules (NF DTU) recommend a control at commissioning but it is not often done. The content defined is:

- Check of the ventilation unit (electrical connections, direction of rotation, stability…)
- Measure of the air flow rate at some air inlets and outlets,
- Visual control of the installation (components and system).

In the case of guaranty policy for existing or new buildings, commissioning and COPREC document is requested by the insurance company. This commissioning is then conducted by the installer, the only one allowed to operate for insurance reasons

To operate commissioning, installer can rely on standards at European level (EN 15239), the RAGE program recommendations (2013), voluntary guidelines like Effinergie and HQE performance protocol, or technical guide “Diagvent” from CETIAT (Vialle, 2005).

Commissioning for residential ventilation systems is generally included in installer training programs and there is no dedicated education or training schemes. Therefore there is no dedicated labelling or certification.

MAINTENANCE AND INSPECTIONS

Unified technical rules (NF DTU) and Technical agreements of DCV systems describe maintenance operations. Maintenance of ventilation system is not mandatory, except for systems designed to extract also combustion products or smoke. There is also no mandatory inspection scheme in France dedicated to residential ventilation systems.

The occupant is in charge of cleaning air inlets and air outlets. In apartment buildings, the owner or the owners association mandates a professional. Several levels of operation exist, from P1 (the less one) to P3. Guidelines are provided by national professional associations (Barbat, 2010).

Maintenance of residential ventilation systems is generally included in installer training program but there is no dedicated education or training schemes. A qualification for ventilation system maintenance companies exists. It is delivered after an administrative exam with possibility of audits in companies and on installations.

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

The quality of the ventilation system has an impact on the building energy performance calculation. First of all certification allows to take into account real performance of the systems whereas products without certification will have penalties on some characteristics (efficiency of heat recovery for example). Then, information on ductwork air tightness class is required for the energy performance calculation, and also the thermal insulation of the part located outdoor. Those characteristics have impacts on heating needs calculation, global efficiency of heat recovery systems and also fans power supply.

The ductwork air tightness class has to be proven by a measurement or by a quality scheme. If it is not reached, then a new energy performance calculation with real value should be done.

Topic	Major causes of quality problems	Existing quality schemes or incentives
Product	Performances announced might be to "optimistic" or do not take into account installation configuration	Certification programs or labelling: NF VMC, CSTBat or Eurovent Certification
Design	- Acoustic problems - Air flow is not sufficient because of ductwork pressure	- The unified technical rules describe design scheme - Labelling of consultants
Installation	- Too much pressure drop of the ductwork because of badly installed flexible ducts (too much elbows, flattened ducts) - Air inlets and outlets of fans that are installed are not the designed ones - Air outlets or fan are not well connected to the ductwork	- The unified technical rules describe installation - Technical guides to ensure air tightness of building and ductwork, and for good ductwork installation - French document FD E 51-767 describes air tightness measurement scheme during installation - High performance building label, linked with RT 2012, will require ductwork air tightness measurement - Labelling of installers
Commissioning	No information available	- The unified technical rules describe commissioning - High performance building label, linked with RT 2012, will be delivered after ventilation commissioning for residential buildings
Maintenance	Air inlets or air outlets are dirty or hidden behind furnitures Filters of balanced systems are not changed in the right time Out of order fans are not replaced	- NF VMC for balanced ventilation systems requires an alarm for filter change - Labelling of maintenance companies (for apartment buildings generally)
Inspections	No information available	No information available

Table 2: 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.

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

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ABSTRACT
Residential ventilation is a developing market and is mainly seen as a core element to reach the 2020 goals in the building sector. Products have reached a high quality level in Germany and the bottle neck for further developments in the market are trained architects, designing engineers and installers. Customers have reservations mainly based on the hygiene and acoustic performance of the systems, where also weak skills and a field for future trainings have been identified.

KEYWORDS
Residential ventilation, market, heat recovery, demand controlled ventilation, hygiene, health, indoor air quality, acoustic, certification, cleaning, inspections.

INTRODUCTION
Since almost 20 years, residential ventilation systems are considered in the German energy savings regulations for buildings, but until 2009 the share in the total market was low. Improved building tightness and the growing rate of building damages and health problems caused by inadequate ventilation lead to the development of the new DIN 1946-6 published in 2009. The described ventilation concept, which is a simplified check of building leakage, lead to a higher transparency of the ventilation needs in a residential building and to a higher responsibility of the designers. It is no longer possible to discuss the aspects of ventilation by addressing it to the responsibility of the user.

RESIDENTIAL VENTILATION MARKET
Mechanical ventilation in residential buildings is a developing market in Germany. Many traditional architects still try to avoid fan systems although they recognise a greater importance of designing ventilation in air tight buildings. In new dwellings (and also in refurbished buildings) a high tightness of the building envelope according to the buildings regulations results in a higher focus on ventilation issues. The main aspects are:

- Preventing the construction from damage and moulding
- Indoor air quality
- Energy efficiency

The general view in current legislative area is that window airing still is a reference, but the view is changing slowly. An energy reference in German ENEV 2009 and draft EnEV 2013 is currently seen in demand controlled exhaust only system, but this is not mandatory for new or refurbished residential buildings.

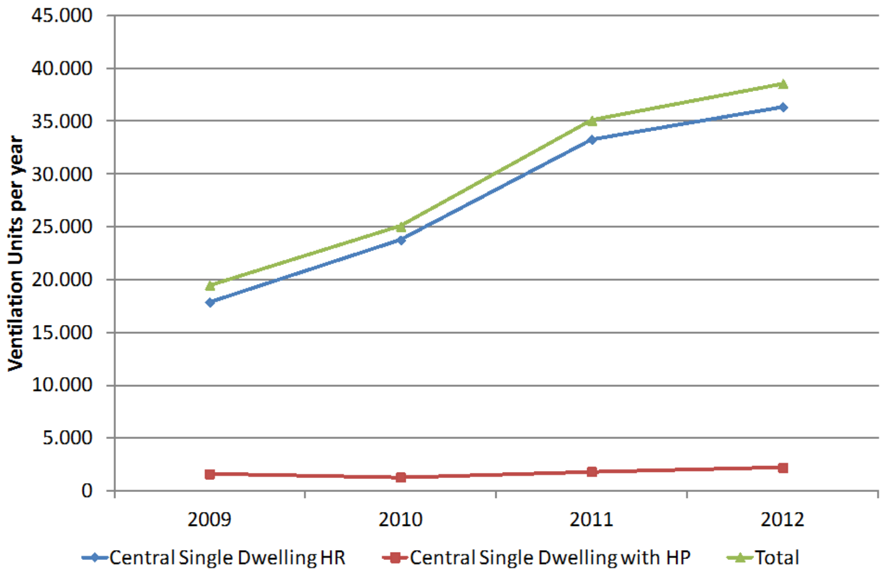

Figure 1: FGK BDH statistic on Residential Ventilation Units with HR for a dwelling.

For bathrooms, toilets without a window, it is mandatory to install minimum an exhaust only system according DIN 18017-3 [3]. These systems are typically designed for short time duty during occupation and do not fulfil the requirements for a whole dwelling ventilation. In these systems ventilation and fire and smoke protection aspects are considered as a combination.
EnEV [1] specifies in §6 that minimum hygienic air volume flows shall be realized. But no exact specification is given. Some judgements say, that this shall be realized without any action by the user, but also no further interpretation exists. DIN 1946-6 [2] is an important tool to calculate minimum ventilation requirements.

There is no complete statistic available for German market. For single dwelling units with heat recovery a statistic is available showing a constant raise of approx. 15 to 20% per year leading to 40.000 units per year now. In Germany also single room units do play a significant role in the market. The detailed sales are not known. The market of exhaust solutions is fragmented into different technologies which are also used in non residential applications.
For high efficient buildings (nearly zero energy, passive house) HR-ventilation is seen as a basic requirement.
Compared to the amount of new dwellings, we estimate that ~30% of new dwellings might have fan assisted ventilation system. The market of refurbishments still is low.

PRODUCTS
Based on the ventilation principles described in DIN 1946-6 (system requirements [2]) different products and systems can be used including natural and fan assisted ventilation systems (figure 2). Infiltration is considered in the calculation of the minimum ventilation rates.

There are 4 different levels of system qualities, defined by minimum requirements for products according to DIN 4719 [4]:

- Standard requirements
- "H" Hygiene qualified systems for a high IAQ-level
- "E" Energy qualified systems for high energy efficiency
- "S" Acoustic qualified systems for high requirements

Higher requirements H, E, S can only be fulfilled with fan assisted ventilation systems.

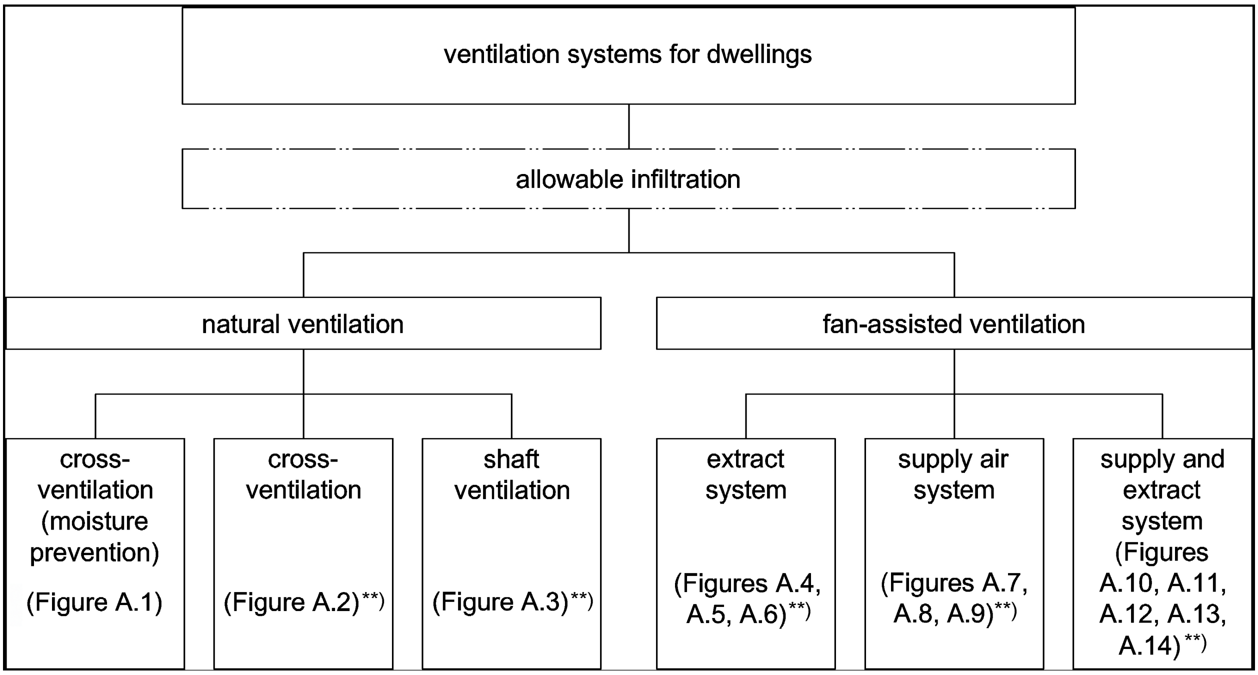

Figure 2: Ventilation systems for dwellings (DIN 1946-6)

There is no single certification, declaration or verification program in Germany because the legal basis is complex. There is not even a single test method. The main programs are:

- DIBt approval
- DIN 4719 declaration based on EN 13141 test and will be revised by EN 13142
- Passive house certification

DIBt is performing the approval since over 15 years according to its own rules considering energy, hygiene and fire safety aspects. Up to now not even the test method of EN 13141 is accepted. It is seen as a basic requirement to fulfil the minimum requirements of German building codes. There is no minimum limitation on energy aspects like heat recovery or fan efficiency.

DIN 4719 is a self declaration [5] system for products based on EN tests and in this aspect fully compatible with the European market. It covers further product requirements not considered in CEN standards but important for ventilation unit quality. This system can be upgraded to a certification program.

Passive house certification is a standalone voluntary procedure for this style of buildings. The core aspect is energy efficiency.

DESIGN, INSTALLATION, COMMISSIONING, MAINTENANCE, INSPECTIONS
Beside all confusing aspects of product approval and certification in Germany, DIN 1946-6 is a general accepted basis for residential ventilation for design, installation, commissioning, maintenance and inspections. The standard delivers many checklists for nearly every aspect.

The standard is the basis for training an education schemes for:

- Architects
- Designing engineers
- Installers
- Service contractors

The standard gives guidance for natural and fan assisted ventilation systems:

- Ventilation concept - Necessity of ventilating measures
- Selecting a ventilation system
- Designing of ventilation systems and components including ducting
- Documentation
- Handover and commissioning
- Maintenance and service including time schedules

The training and education programs in Germany are voluntary programs and no general certification for persons nor for companies exists besides the established system of apprenticeship. The professional organisations and the system providers (manufacturers) typically offer a two days continuing education and training including all the important aspects, which we see as a minimum requirement.

Aspects for the training are:

- Basic requirements for residential ventilation
- Technologies
- Components
- DIN 1946-6
- Design aspects
- Condensate and frost protection
- Installation
- Controls
- Service

Residential ventilation systems for single dwellings are mainly designed and installed from installation companies supported by manufacturers with small support of architects. Installers do have a great responsibility but we still see that only a small percentage of possible installers have been trained in an adequate way (< 20%).
In further developments of training schemes, skills on hygiene, health and acoustic aspects must be added in the training plans.

CERTIFICATION OF CLEANING
Hygiene aspects are recognised as an important aspect for residential ventilation systems [6]. Fachverband Gebäude-Klima e.V. developed a certification program of companies for maintenance of ventilation systems including the cleaning of residential ventilation systems. The certification program [7] considers:

- Knowledge and standards
- References
- Insurances
- Quality
- Training of stuff
- Availability of specialised tools
- Laboratory equipment for hygiene tests
- Documentation
- Health and safety protection at the workplace
- Personal protection devices
- Social responsibility

Figure 3: Certification for Duct and System Cleaning

Certified companies are allowed to show the label in Figure 3.
A simplified questionnaire has been developed, to allow customers to request for duct cleaning and companies to make a quick calculation to offer the service for a reasonable price.

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

In EPBD calculations (German EnEV and DIN V 18599), most of the important energetic aspects are covered:

- Electrical consumption of fans
- Smart controls, DCV
- Heat recovery

Leakage of units is part of the product requirements, but leakage of ductwork is not considered.

Incentive programs define minimum requirements above the "standard values" mainly based on regional definitions. Passive house certification or DIN 1946-6 and DIN 4719 "E" self declaration are widely used as a basis together with DIBt approval. Checks of independent "Energieberater" are mainly mandatory in the incentive programs.

CONCLUSION

Products and design tools have a high qualitity standard in Germany. DIN 1946-6 is a suitable basis for further trainings. Facing the targets of a nearly zero energy house in 2020 residential ventilation has to be further developed in planning process. The trained specialists operating in design process are a limited number and one of the key obstacle for further developments.

Hygiene and acoustic aspects must be a field for further development and trainings.

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[5] FGK-STATUS-REPORT 29: Einheitliche Herstellerdeklaration für Wohnungslüftungsgeräte nach DIN 4719
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http://www.downloads.fgk.de/129_SR9_Hygiene_KWL_.pdf

[7] FGK-STATUS-REPORT 13: Zertifizierung Instandhaltung und Reinigung von RLT-Anlagen
http://www.downloads.fgk.de/144_SR_13_Zertifizierung_V9_120716.pdf

QUALITY OF VENTILATION SYSTEMS IN RESIDENTIAL BUILDINGS:

STATUS AND PERSPECTIVES IN THE NETHERLANDS

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ABSTRACT

Standard mechanical ventilation has been used since the seventies in residential buildings in the Netherlands. Residential ventilation has attracted negative publicity several times over the last few decades, with people establishing a link between residents' problems and deficient ventilation facilities.
This triggered large-scale studies into the quality of ventilation facilities in residential buildings. These studies illustrate that errors are made in all phases of the construction process, from initiation phase to maintenance. This has resulted in many dwellings suffering inadequate system capacity, with imbalances in air distribution between living areas and too much noise from mechanical ventilation systems.

Legislation in the Netherlands stipulates performance requirements. This legislation – the Netherlands Building Code [1] – refers to standards that state how to comply with the performance requirements. In addition to the legislation and the standards, the Netherlands has sector-specific guidelines. Though these guidelines are not legally binding, they do stipulate the level of technology applied in the sector. Recent studies [2] show that more than 50% of new dwellings fail to comply with one or more legally mandated performance requirements.

To improve the quality of ventilation facilities in dwellings, various initiatives have been taken. However, legislation has not been tightened, as the government believes that market parties themselves should provide a solution to the quality issues detected.

The knowledge of the correct design, fitting and maintenance of such systems is summarized in practical reference works. Additionally there is an extensive array of training options, and installers can obtain certification. In practice though there is still too little use made of training options and certification.

In 2012, together with stakeholders from the building industry, the government agreed an action plan [11]. The action plan is signed by representatives of architects, clients, builders, fitters, consumer organizations, manufacturers and government.

The action plan describes activities in all phases of the construction process that taken together must ensure better ventilation facilities in new houses. The key elements are:

1. Use a clear programme of requirements when commissioning;
2. Supervise execution using a protocol;
3. Establish quality at delivery using a completion certificate (VPK = Ventilation Performance Assessment);
4. Inform residents using a user manual;
5. Organize trainings for architects, builders, installers and others;
6. Increase resident awareness.

Concrete aids have been developed for all these steps. The government holds market parties responsible but checks progress through active monitoring.

KEY WORDS
Residential ventilation, legislation, commissioning, assessment guidelines, action plan, quality

INTRODUCTION

This document describes the state of affairs on the quality of residential ventilation in dwellings. Firstly by describing the market and the products for residential ventilation in the Netherlands. Then explaining step by step the manufacturing process of ventilation systems in dwellings. Not specifically from a technical point of view, but primarily in terms of the developments that are required.

Table 1 gives a summary of the problems relating to the quality of ventilation systems in dwellings. It also indicates for each phase in the process which solutions (certification schemes) are implemented or under development to prevent these problems happening in future.

Topic	**Main causes of quality problems**	**Existing quality schemes or incentives**
Product	n/a	No
Design	Insufficient capacity, no ventilation balance	Yes, BRL 6000-10
Installation	Incorrect location of valves, no silencers, volume flows not set, ventilation channels not clean, incorrect assembly of air ducts	Yes, BRL 6000-10
Commissioning	Not often applied	Yes, BRL 6000-10 and BRL 8010
Maintenance	Contamination in installed system, no maintenance by resident	Yes, BRL 8010
Inspections	Incorrect use	Yes, BRL 8010

Table 1: 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

RESIDENTIAL VENTILATION MARKET

The Netherlands has built up a strong reputation in residential ventilation. Innovations in the Netherlands, such as heat recovery and on-demand ventilation, are for the first time being applied on a large scale. Due to the large-scale application of ventilation systems in dwellings, a great deal of information is available on the quality aspects of design, installation, use and maintenance. Various studies were carried out in response to complaints from residents. These studies investigated the quality of ventilation systems and the relationship between that quality and any impacts on health.

Mechanical ventilation systems have been used since the seventies, and are now fitted in roughly three out of every ten Dutch homes. From the eighties onwards, more and more homes were fitted with central balanced ventilation, called balanced ventilation in practice. At this point in time, 2% of homes are fitted with balanced ventilation.
All new dwellings are equipped with a mechanical ventilation system. Natural supply and mechanical exhaust and balanced ventilation with heat recovery are the most common systems in new construction. Mechanical decentralised ventilation systems, with ventilation being regulated separately for each room, are becoming more popular. Exact figures on the distribution of this system in new homes are not available.

Ventilation system classification

The most popular ventilation systems on the Dutch markets are divided into the method of supply and/or exhaust: natural or mechanical.

This results in the following main divisions [12, 18]:

- System A: natural air supply and natural air exhaust;
- System B: mechanical air supply and natural air exhaust;
- System C: natural air supply and mechanical air exhaust;
- System D: mechanical air supply and mechanical air exhaust.

Also being introduced is [4, 16]

- System X: system combinations in a single dwelling.

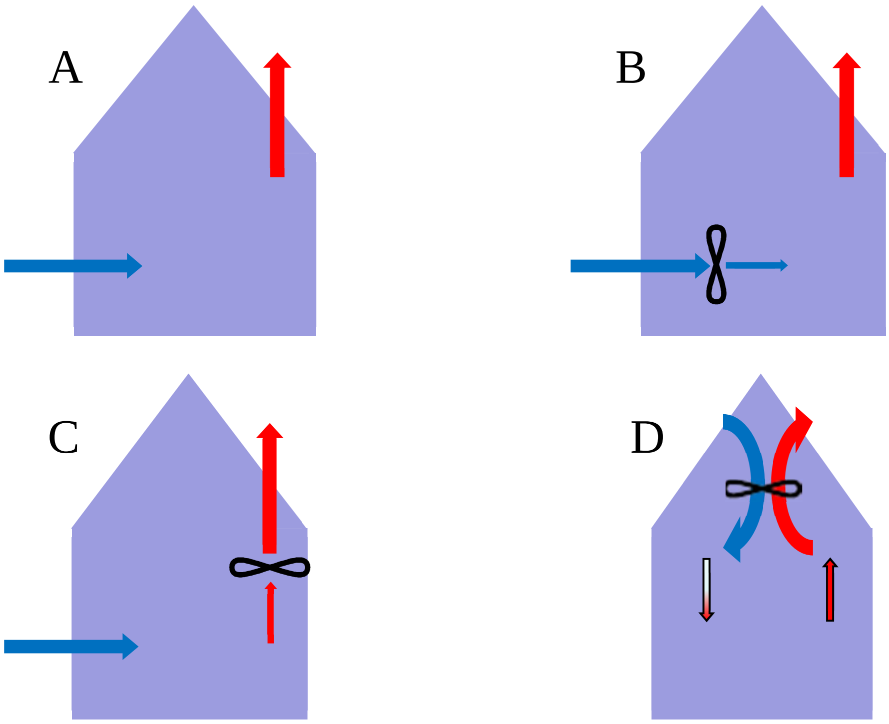

Figure 1: Ventilation systems A, B[1], C and D

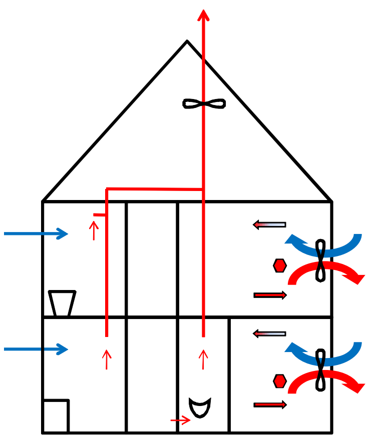

Figure 2: System X, variant [9] with type D decentralised, heat recovery, CO_2-control combined with type C

[1] Ventilation system B appears in very limited numbers in the Netherlands, and is not elaborated on further in this document.

All sorts of variants are applied within the main classification stated above. These variations relate to the location of supply/exhaust (centralised or decentralised), the control method (manually, time, CO_2 on-demand) and whether or not heat recovery is fitted. In the standard [16] and the technical reference [5] these are indicated by a sequence number or letter.

Legislation and regulations
Legislation for residential ventilation is stipulated in the Netherlands Building Code [1]:
A building to be constructed has a ventilation system that prevents poor indoor-air quality that might result in adverse effects on health.

The Netherlands Building Code contains minimum performance requirements that must be complied with. No requirements are thus stipulated for ventilation systems in new dwellings.
However, the Netherlands Building Code refers to standards that state how to comply with the performance requirements stated in the Code. These standards are drawn up by the Netherlands Standards Institute (NEN). In addition to the legislation and the standards, the Netherlands has sector-specific guidelines. Though these guidelines are not legally binding, they do stipulate the level of technology agreed in the sector.

Investigating ventilation system quality
Over the last few decades, many studies have been carried out into the quality of residential ventilation. One study [2] commissioned by the government revealed that over 50% of the homes completed failed to comply with one or more of the minimum performance requirements in the Building Code. The main shortcomings detected by the study were:

- Insufficient capacity
- Incorrectly mounted ducting
- Systems not set
- Absence of silencers
- Contamination in system
- Illogical location of supply vents
- Incorrect use by residents
- Inadequate information to residents
- Poor maintenance of the system

RESIDENTIAL VENTILATION PRODUCTS
A ventilation system is made up of various components. For some time now in the Netherlands residential ventilation producers have been shifting from component supplier to system supplier. This is resulting in a supply of well-coordinated components.

Ventilation product quality
A good system always starts with high-quality components. There is no system for certifying components in the Netherlands. However, there is agreement on the most important specifications of components and systems. The sector association for suppliers of air-processing technology (the VLA) has made agreements on the method of presenting specifications to avoid confusion among customers.

Knowledge is a precondition of quality
Manufacturers are acutely aware that they play a key role in the entire installation process. Many manufacturers not only see themselves as a supplier of products, but also as suppliers of expertise. Sharing expertise is done through training courses for advisors and installers and through coaching advisors in the design phase of the system.

Development of knowledge of course goes hand in hand with technological development. Innovation programmes aim at the development of robust systems. Robustness encompasses the minimisation of sensitivity to resident behaviour, (system) design, realization, maintenance and obsolescence.

DESIGN

Legislation and regulations

The basis for designing (mechanical) residential ventilation systems lies in the Building Code. This includes the following minimum performance requirements:

- Ventilation capacity in living areas, wet areas, kitchen and other areas
- Thermal comfort, prevention of draughts
- Controllability of the ventilation system
- Air quality, such as location of opening, flow direction and dilution
- System noise levels (maximum permissible)
- Energy efficiency, expressed in energy performance coefficient (EPC)

To ensure compliance with the performance requirements, the Netherlands Standards Institute (NEN) has issued a number of standards with specification methods. In these terms, the following design standards from the Building Code are relevant:
NEN 1087 Ventilation of buildings – Specification methods for new constructions [12]
NEN 8087 Ventilation of buildings – Specification methods for existing buildings [17]
NEN 2757 Supply of combustion air and extraction of smoke from combustion units in the building – Specification of methods [13]
NEN 5077 Sound proofing in buildings [14]
NEN 7120-1 Energy performance of buildings – Specification method [15]
NEN 8088-1 Specification method for ventilation flows for NEN 7120-1 [16]

Designed in practice

In practice, it is not always easy for parties to realize a good design on the basis of these basic principles. A number of frequently occurring design mistakes in practice are:

- Maximum performance in the design is based on the minimum performance requirements in the Building Code. In practice, there is no margin for minor deviations in the design;
- Ventilation balance taken across the dwelling is out of sync, discrepancies between supply and exhaust capacity;
- Unnecessary bends in air ducts and flexible connectors in mechanical ventilation systems;
- Insufficient space free to carry out maintenance effectively (e.g. replacing air filters in a heat recovery unit).

It doesn´t get any easier with the arrival of new, innovative, residential ventilation systems. The demand for expertise has increased rapidly.
The performance requirements in the Building Code and the above-mentioned standards are in practice not stringent enough to ensure the design of high-quality systems.

Technical standards and references

For these reasons, different technical guidelines and manuals have been developed.
To comply with the performance requirements in the Building Code, the Dutch ISSO Building Services Research Institute has developed technical references for the installation sector in the Netherlands for designing, realizing, inspecting and maintaining residential ventilation systems.

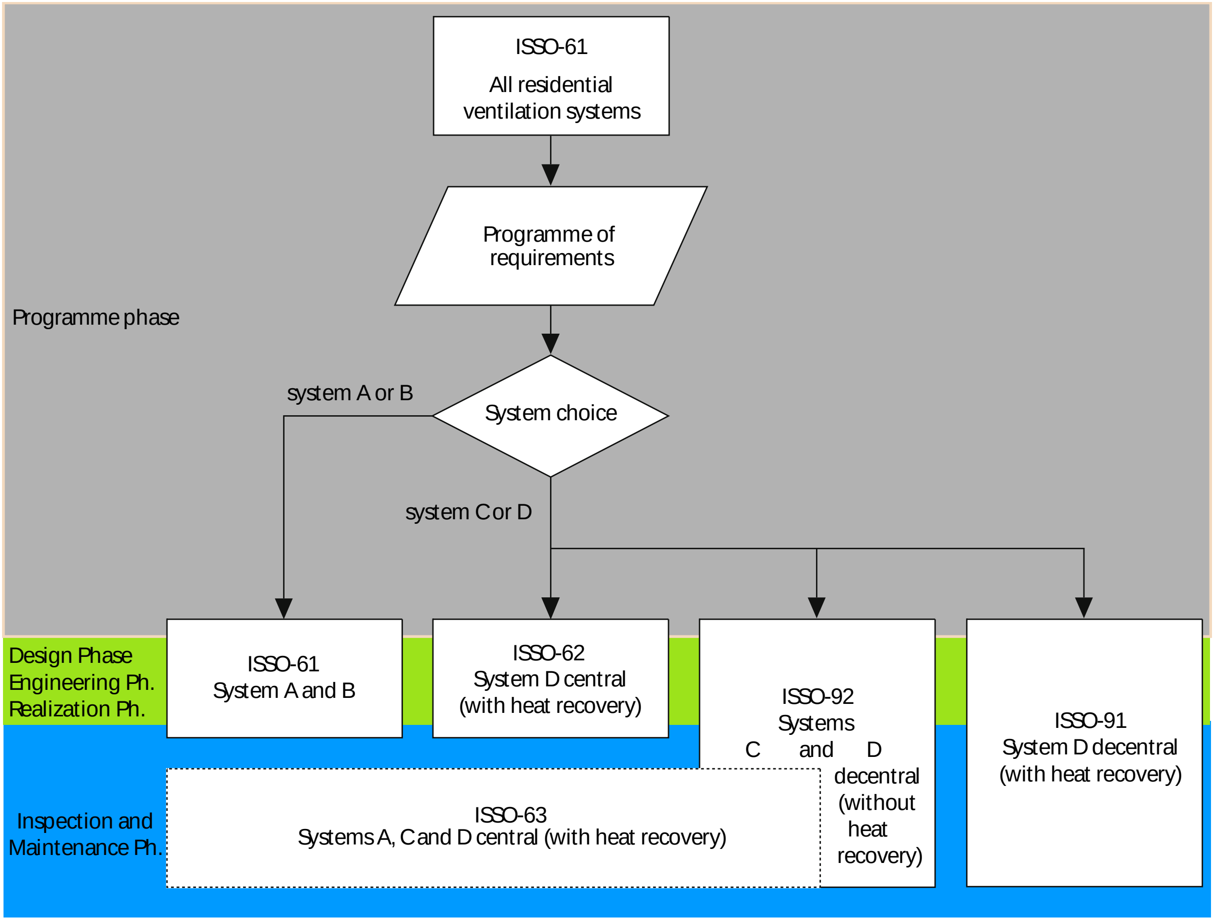

Figure 3: overview of technical references for residential ventilation

The so-called ISSO publications are generally recognized by the Netherlands installation and ventilation sector and are applied in the design of residential ventilation.

The starting point is formed by ISSO publication 61 [5], with which a system can be selected in combination with a software tool [6].
Depending on the system selected, this publication and/or other publications can be used to design a well-functioning residential ventilation system. For high-quality ventilation systems, each publication states quality requirements in addition to the statutory requirements.
This relates to contract law based quality requirements that might consist of:

- Supplementary capacity requirements, such as for storage areas, utility areas for washing machines, and lofts not being marked as occupied zone;
- Supplementary requirements for system noise levels in living areas;

All expertise in the ISSO publications relating to residential ventilation is summarized in the practical pocket book Kleintje Ventilatie [4].

Educational programmes and courses
To apply the developed expertise in practice, education is essential. For this reason, in 2011 the sector developed a course on residential ventilation, comprising 5 modules:

1. Basic module
2. Module design
3. Module fitting and installing
4. Module inspection and maintenance
5. Module system assembly (training manufacturers)

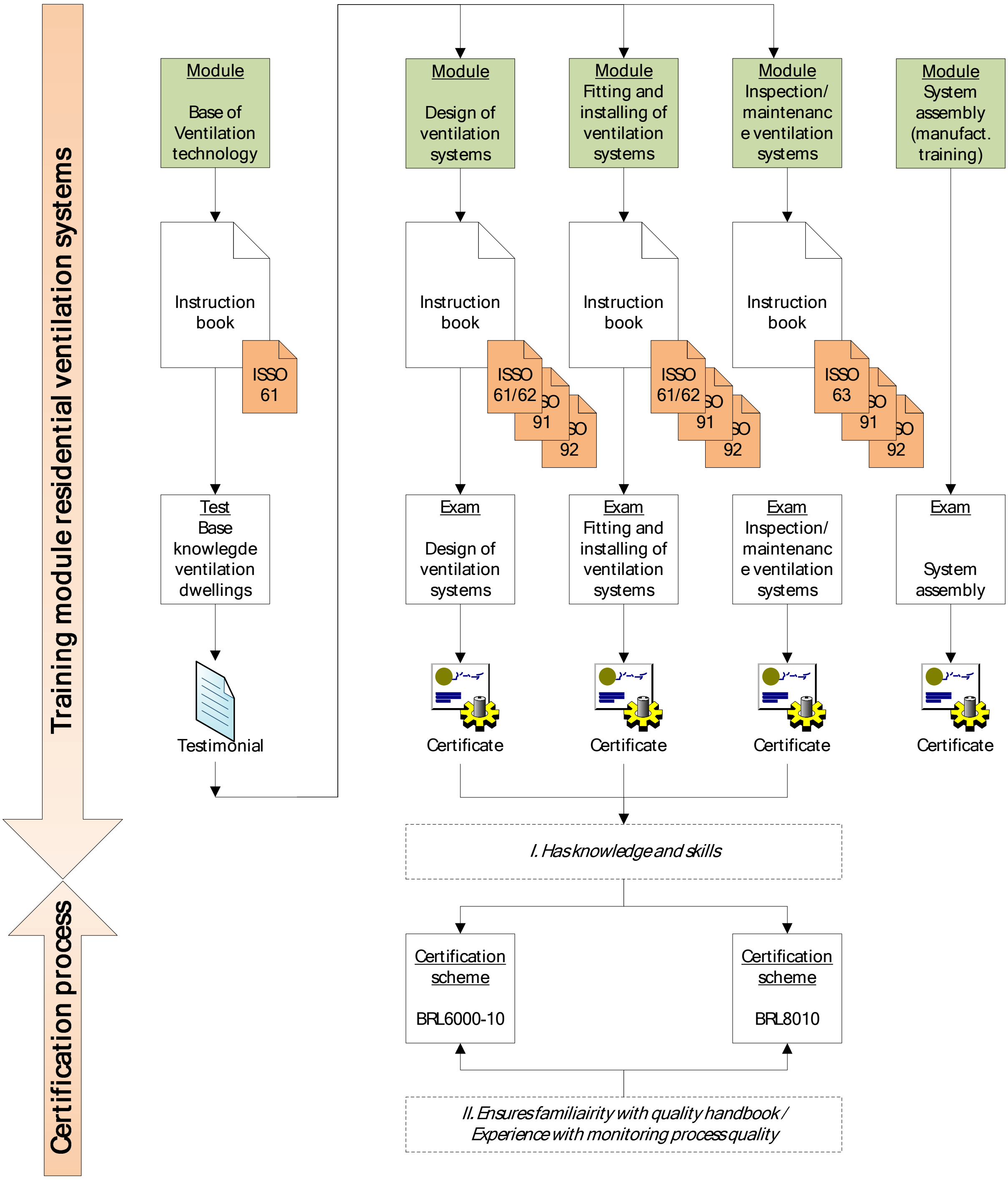

Figure 4: Training modules for residential ventilation

Each module is made up of at least the following parts:

- Graduation documents with learning goals, definitions of target groups, per level and (construction) discipline;
- Instruction book per module, coordinated to the developed ISSO publications;
- Tasks and case studies for written exams;
- An exam to graduate from the completed training course, conducted by an independent examination agency [3].

INSTALLATION
In the realization phase, the ventilation system is installed and commissioned.

Installation in practice
A number of frequently occurring installation mistakes in practice are:
- Ventilation ducting is incorrectly mounted or is not clean when being fitted;
- Flexible ducting is incorrectly fitted, creating unnecessarily large air resistance and thus energy losses;
- Incorrect fitting of supply valves;
- No sound proofing facilities included in the mechanical ventilation system;
- System not set up after fitting.

Figure 5: Poorly working system due to incorrect use of flexible connectors

Commissioning
One key step after the installation is to control correct operation of the system.
One quality requirement in technical references is that a commissioning report is drawn up at commissioning to include the following information:
- Design specifications and any deviations relating to the design specifications;
- Assessment report on fitting and installation;
- Test reports relating to:
  - The air-volume flow control button;
  - Air-volume flows;
  - Air leakage (if necessary only visual control);
  - Sound levels (indicative).

End users must be given a user manual at commissioning and for proper use.
One quality requirement in technical references states that the user manual must contain at least the following factors:
- Description of the operation;
- Operating guidelines;
- Maintenance guidelines;
- What to do in case of malfunctions;
- Details of the supplier and installer.

To make it easier for users, the sector association for installation companies, Uneto-VNI, set up the portal www.mijnhuisinstallatie.nl [21]. Here installers can compile, print and give to the user/owner the user manual on the basis of the system present in the dwelling.

If the ventilation system is commissioned in accordance with BRL6000-10 [19] or BRL8010 [20], then the requirements of a commissioning report and user manual are complied with automatically.

COMMISSIONING

Under commissioning we mean a phased process aimed at managing the quality and safeguarding the performance of residential ventilation.

The policy of the Dutch government aims towards deregulation. This means that demonstrating a certain quality is no longer regulated by law. The government expects market parties to make clear agreements to safeguard the quality of ventilation systems, one means being certification. Certification is the procedure by which an independent third-party, usually a certification organization, grants in writing that a product or service complies with the established requirements.

Commissioning programme phase

When requesting a building permit for a dwelling, a ventilation calculation is required by law. With this calculation, it must be made plausible that it will comply with the minimum capacity requirements as stated in the Building Code. The municipality's task when granting permits is to check the ventilation calculation. In practice, this is a limited test that does not guarantee that a ventilation system does what it should do.

Commissioning design and realization phase

To clarify quality at the design, installation and/or inspection of ventilation systems, a certification scheme has been in existence in the Netherlands since 2006.
Assessment Directive BRL 6000-10 [19] applies to residential ventilation. This directive has two parts:

1. Requirements for the installation company;
2. Design and installation of ventilation facilities in dwellings.

Installations fitted in accordance with the directive are certificated.
Only a few companies in the Netherlands are certified to do this.

Commissioning inspection phase

To assess the commissioned residential ventilation facilities, the Ventilation Performance Assessment (VPK) [20], developed in 2009, can be applied. This assessment offers (installation) companies the option of assessing the quality of realized ventilation facilities in certificated homes. A VPK involves checking whether the design complies with the guidelines, whether the system is fitted in accordance with the design and whether the intended performance has actually been achieved. Furthermore, an assessment is made of whether the system can be effectively maintained and that the residents are correctly instructed. The VPK can be used for all available ventilation systems, though it is not stipulated by law.
The way of working is established in an assessment guideline managed by the Dutch Installation Sector Quality Assurance Foundation (KBI). Companies can get themselves

certificated to carry this out in accordance with the assessment guideline. There are currently seven certified companies. Despite the fact that the VPK is supported by the government, demand for the VPK is still limited. The non-obligatory nature of the assessment undoubtedly plays a major role in this. At the moment, there are also no supplementary financial incentives to engage a certified company. Subsidies for energy sustainability can be obtained, for instance, without requiring a certified company to carry out the work.

In practice, the VPK appears to be effective. It establishes contractually that the ventilation facilities must comply with the agreed requirements. The VPK is used to assess whether this is the case. The parties are aware that there are consequences for those that do not comply with the requirements.

Action plan for ventilation quality improvement 2015 [11]
As stated earlier, many studies have been done in the Netherlands into the quality of residential ventilation. These studies demonstrate that the shortcomings in ventilation systems arise in all phases of construction: from design up to and including the use and maintenance by residents. As a result, the government made agreements with the trade stakeholders in 2012 that were then set down in the residential ventilation action plan. Good final quality in terms of ventilation capacity, distribution of ventilation capacity, noise levels, information flows and user-friendliness of ventilation systems can only be realised if they are controlled in all phases of the construction process.
This is shown graphically in figure 6.

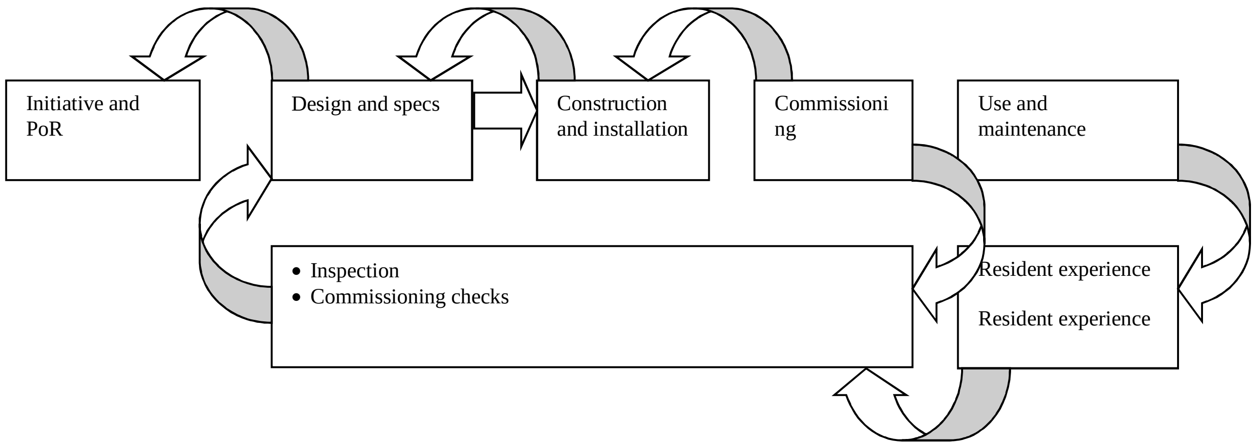

Figure 6: phases and feedback on progress of installation process

The action plan is signed by representatives of architects, clients, builders, fitters, consumer organizations, manufacturers and government.
The plan describes activities in all phases of the construction process that taken together must ensure better ventilation facilities in new houses. The key elements are:
1. Use a clear programme of requirements when commissioning;
2. Supervise execution using a protocol;
3. Establish quality at delivery using a completion certificate (VPK);
4. Inform residents using a user manual;
5. Organize trainings for architects, builders, installers and others;
6. Increase resident awareness.

Concrete aids have been developed for all these steps. The government holds market parties responsible but checks progress through active monitoring. The first results of the action plan will be made known over the course of 2013.

INSPECTION AND MAINTENANCE

Maintenance in practice

In practice, maintenance of a (mechanical) ventilation system often gets too little attention, while it is essential for keeping the system functioning at its required performance level. A good maintenance plan is key to this. However, there is no obligation to draw up a maintenance plan for residential ventilation.

One key element of the maintenance plan is the maintenance activities. Table 2 provides a summary of the most common parts requiring maintenance. It also indicates who should carry out the maintenance, the resident or a professional (installer/maintenance company).

Topic	**Maintenance by**		**Type ventilation system***		
	Resident	*Professional*	*A*	*C*	*D*
Facade grilles and valves	X	X	X	X	X
Air ducts		X	X	X	X
Heat recovery unit	X	X			X
Extractor unit / roof fan		X		X	X
Facade ventilation unit	X	X			X
Control + testing		X		X	X
Air filter	X	X			X
Silencer		X			X

Table 2. Overview of maintenance components for ventilation systems in individual dwellings and residential blocks

Technical standards and references

For (centralized) mechanical ventilation systems in houses and residential buildings, ISSO-63 [8] provides a detailed procedure for correctly drawing up and carrying out an inspection and maintenance plan for residential ventilation systems.

INFLUENCE OF VENTILATION-SYSTEM QUALITY ON ASSESSMENT (+/-) OF BUILDING ENERGY PERFORMANCE

There is currently no link between the Energy Performance Coefficient [15] of a new home and the actual quality of the ventilation system. The standard for a ventilation test [16] to assess energy performance assumes a ventilation system installed in accordance with BRL 8010.

In mid-2013, the Energy Label for new residential buildings is expected to become legally mandatory. The scope of this energy label is wider than the scope of the EPC as related specifically to installation quality:

Before an energy label is granted, the systems fitted must be checked and verified using the basic principles from the EPC.

For ventilation, this relates to the following aspects:

- Type of ventilation system;
- Control of ventilation system. In the case of on-demand ventilation (type C or D), check whether a central control unit is present in the dwelling;
- Heat recovery efficiency.

Furthermore the quality of the ventilation system can be optionally assessed by carrying out a performance test, using the VPK for example. Although it is not mandatory, the expectation is that more and more parties will opt for this optional performance test before issuing an energy label for a new home. It generates confidence in the operation and quality of the ventilation system that is being commissioned.

CONCLUSIONS

There is a great deal of expertise in the Netherlands on the best way to design, install and maintain residential ventilation systems. This expertise is available to all market parties, yet application of this expertise in practice is more intractable.

The performance requirements which residential ventilation has to comply with are legally mandated. The government sees a limited role for itself in enforcing these requirements and is of the opinion that market parties should bear joint responsibility for good operating quality. There are certification programmes by which installers can demonstrate that they supply high-quality systems. Since demand from the market is limited, few installers bother getting themselves certified.

Complaints from residents and various studies have demonstrated that the operating quality of many residential ventilation systems is simply unacceptable. Lead by the government, an action plan has recently been drawn up in which agreements have been made to safeguard the quality of residential ventilation systems in new homes. 5All trade stakeholders – from architects to suppliers – have signed this plan. The key elements are:

1. Use a clear programme of requirements when commissioning;
2. Supervise execution using a protocol;
3. Establish quality at delivery using a completion certificate (VPK);
4. Inform residents using a user manual;
5. Organize trainings for architects, builders, installers and others;
6. Increase resident awareness.

Concrete aids have been developed for all these steps.

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

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ABSTRACT
Balanced mechanical ventilation with heat recovery and low fan power is now standard in all new buildings in Norway, while facade airtightness has improved. The introduction of passive-house-standard building regulations in 2015 will therefore not incur significant changes to the market. The Norwegian building trade has many decades of experience with mechanical ventilation, and has a system of training, suppliers and contractors. Home owners are generally satisfied with the technology. However there remain specific challenges related to quality of execution and commissioning of installations, due to lack of professionalism. The main issues that homeowners complain about are ventilation system noise, poor kitchen hood catchment and odour. Most homeowners' seem to be diligent at regard to servicing (filter changing etc.) but we nevertheless need measures such as filter alarms, filter subscription schemes and servicing contracts. For apartment buildings, it is sensible to have professionally serviced central air handling unit instead of individual units in each apartment, though this poses challenges in terms of fire safely, cross-talk noise, flow control, and odour from neighbours.

KEYWORDS
Ventilation, Dwellings, Indoor air quality, Maintenance and operation, Norway

RESIDENTIAL VENTILATION MARKET

Changes in building- and ventilation practices

Before the 1970s, houses had natural ventilation. Building research conducted at the time, and since, has led to the use of increasingly impermeable vapour barriers inside the thermal envelope, and increasingly moisture-permeable but wind-tight barriers on the outside. This spurned the introduction of mechanical exhaust ventilation in the 1970s. Balanced mechanical ventilation with heat recovery (HRV) appeared in houses at the same time, after the oil crises, and the number of houses with HRV grew steadily by about 25% annually (i.e. doubling the number of installations every 3 years). This growth was motivated more by a desire for better indoor air quality and comfort in dwellings, than for energy performance. A growing number of HVAC suppliers and builders acknowledged that it is not possible to guarantee that natural- or mechanical exhaust ventilation meets the building regulations requirements for dwelling ventilation all the time. By 2007, 60% of houses and 25% of apartment buildings had HRV, the remainder had mechanical exhaust ventilation. Prior to 2007, there were no energy-performance (EP) requirements for residential ventilation in the building regulations, so it was in principal possible to comply with any form of ventilation system in dwellings, so long as it provided the required flow rates. But after the building regulations were revised in 2007, in compliance with EPBD, the EP requirements virtually dictated the use of HRV in all buildings.

Present building regulations

The building regulations (byggeregler.dibk.no) give functional requirements, whilst the accompanying guidance notes describe some 'pre-accepted' technical solutions.

Indoor climate: The minimum requirements for indoor climate and ventilation rates remain largely unchanged since 1997, and are harmonized with EN 15251. For dwellings, a mix of Class II & III presently suffices (0.5 ach, 7 ℓ/s per person in occupied bedrooms, and minimum extract flow rates from wet rooms & kitchen hoods). The minimum requirement for noise in occupied rooms is $L_{p,\text{Time-averaged}} \leq 30$ dB(A), $L_{p,\text{Fast,Max}} \leq 32$ dB(A), and Room Criterion RC ≤ 23 (similar to ANSI S12.2) from Norwegian Standard NS 8175:2012.

The guidance notes say that operative temperature should not exceed 26 °C for more than 50 hours/year. However, the adaptive thermal comfort approach in EN 15251 is in practice accepted for dwellings when effective window airing is non-problematic. There are also requirements related to radon and moisture-damage prevention.

Energy: The regulations give two alternatives for checking compliance with the energy performance (EP) requirements for building permits. They are:

(a) A simple checklist of measures, including air-to-air HRV with an annual-mean efficiency of $\eta_T \geq 70\%$, specific fan power $SFP \leq 2.5$ kW/(m³/s) ≡ kPa, and airtightness $n_{50} \leq 2.5$ ach for houses; and 1.5 ach for apartments, Wall U-value 0.18 W/m²K (equivalent to 25 cm of insulation), etc. It is relatively easy to control compliance.

(b) Or use software to calculate annual net total energy demand, in accordance with national standard NS 3031. Calculated energy shall not exceed limits given in the regulations [e.g. 115 kWh/(m²yr) for apartments]. It is impossible to verify compliance of this criterion after a building is completed, as energy use is highly dependent on behaviour.

With both routes of compliance, the assumed heat recovery efficiency shall be a true sensible-heat thermal efficiency of the ventilation system as a whole (corrected for imbalance) and corrected for defrosting energy in accordance with the calculation standard (NS 3031).

Although the checklist-approach (a) prescribes the use of air-to-air HRV, the alternative route (b) accommodates all types of ventilation system, including natural ventilation. In practice, however, the route (b) is so strict that heat recovery is generally required to comply. Route (b) is also be used for ventilation units with integrated heat pumps (air-to-air or air-to-water).

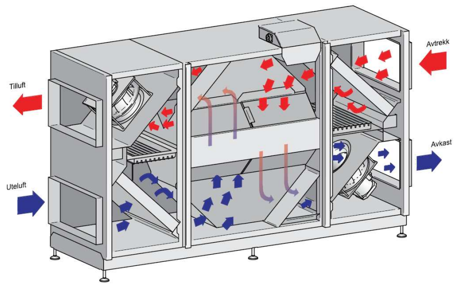
Market effects of the building regulations

In 2002, about 60% of installed residential HRV systems had plate heat exchangers, 25% regenerative heat exchangers (24% reciprocating and 1% rotary), and the remaining 8% air-to-air heat pumps. Rotary heat exchangers were already standard in non-residential buildings. Typical residential HRV fan power was maybe SFP≈2,5 to 3 kPa.

As a result of the 2007 building regulations, practically all new dwellings now have HRV with at least 70% efficiency. We have moved away from plate heat exchangers, due to their high defrosting energy, to more rotary heat exchangers. Also, EC fan-motors became standard. Residential HRV units on the market today have regenerative (mostly rotary) heat exchangers with up to over 80% efficiency, and SFP of 1.5 kPa (Figure 1a & b). Ductwork is mostly circular steel spiro-duct (Figure 2). Rotary heat exchangers are unsuitable for central systems in multifamily buildings, due to the recirculation of water-soluble odour, so contraflow heat exchanger systems with effective defrosting have appeared (Figure 1c).

(a) HRV unit for a house, with bag filters, rotary heat exchanger and EC fans. Foto © Systemair AS

(b) HRV unit for small apartments with rotary heat exhanger and EC fans. 30 dB(A). Foto © Flexit AS



(c) Central HRV unit suitable for apartment buildings, with contraflow plate heat exchanger with defrost function suitable for Nordic climate, giving $\eta_{yr} \approx 80\%$. SFP can be as low as 1.5 kPa. Illustration © Novema AS.

Figure 1: Examples of various HRV units currently on the market.

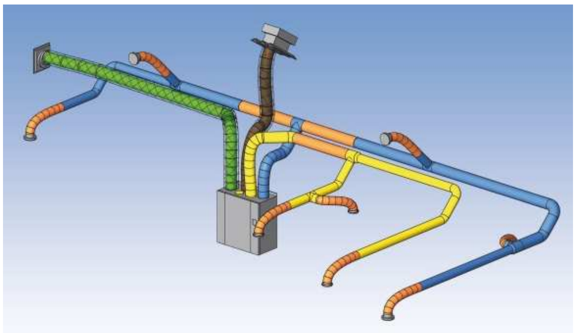


Figure 2: Example of HRV system for a house. Wall air-intake, and exhaust outlet to the roof, prevents short-circuiting, both ducts thermally insulated with vapour barrier to prevent condensation. Main ducts are 160 mm spiral-seem circular steel ductwork, and terminal ducts are 125 mm, giving low flow resistance and noise. Tees are pressed fittings instead of in-situ collar saddles. Acoustic short flexible aluminium ducts at air terminals, while fan noise is attenuated by silencers at the unit. Kitchen hood extract is separate, preventing recirculation of odour, or soiling of the HRV unit. Illustration © Systemair

Compliance control

Control of the regulations is the responsibility of the municipality where the building is located. In the case of housing, this is often just an administrative check that all forms and reports are submitted by the builder. Local authorities do not necessarily have the resources or competence to check the validity of the underlying documentation, so in practice the system is largely based on trust. In 2010, a revision of the law made the control system more stringent, enforcing obligatory third-party site inspections of all buildings. However for houses, only airtightness is measured, while the ventilation system is not checked.

The National Office of Building Technology and Administration (www.dibk.no) administers a national register for authorizing companies (designers, contractors and controllers) in 18 different categories, such as HVAC or fire-protection, each with three grades of competence. Each company can be registered in multiple categories. If a company shows significant negligence or incompetence, it can be given a fine or lose its category/competence status.

The main motivation for builders to provide quality is thus to avoid civil litigation by the building owner. Much noncompliance is probably due lack of competence, but profit margins in the building industry are small, so there is some wilful corner-cutting by builders who exploit the superficiality of the authorities' control and the homeowner's unawareness. Homeowners rarely have a means of measuring ventilation rates or noise levels.

Eriksson (2008) and Schild (2010) give more details on the regulations and compliance.

FIELD STUDIES ON SYSTEM QUALITY

The most recent national field- and laboratory study of the quality of balanced HRV systems in houses (detached, semi-detached or terraced) was conducted by Schild (2003). The questionnaire asked about IAQ, technical features, usability, and maintenance, and energy consumption. The number of responses (257) provided a representative cross-section of the national stock at the time. Most (89%) of the respondents were satisfied or very satisfied with their balanced ventilation system as a whole. This is better than an earlier study including mechanical exhaust systems (Blom 1995).

Only 38% of the duct systems were mainly spiro-duct. This was disappointingly low. The rest had mainly flexible ducts. The study showed that spiro-ducts have several advantages, except for the additional cost of about €400 per dwelling.

In most of the systems (82%), the kitchen hood exhausted directly to outside though its own duct. This is good as it avoids soiling the HRV unit or recirculating odour.

Half of the HRV units were attic models, the remainder being cabinet models located mainly in unoccupied heated rooms (e.g. washroom), and few were located in basements (4%) or integrated over the kitchen hood (4%). This was a good development from an earlier field study (Blom 1995) in which more of the units were fitted in the attic. Placement in cold attics makes servicing access more difficult, and can significantly increase duct heat loss.

Indoor environment

Perceived IAQ: 90% of the respondents were satisfied or very satisfied with the IAQ. In comparison, in a national phone survey conducted in 1999 (500 respondents), 77% of respondents said that IAQ was good or very good for houses with natural- or mechanical exhaust ventilation. One can criticize the statistical merit of these surveys, but the fact that balanced ventilation is an effective means of ventilation is also borne out by other Nordic field studies of air change rate in homes with different ventilation strategies (Figure 3).

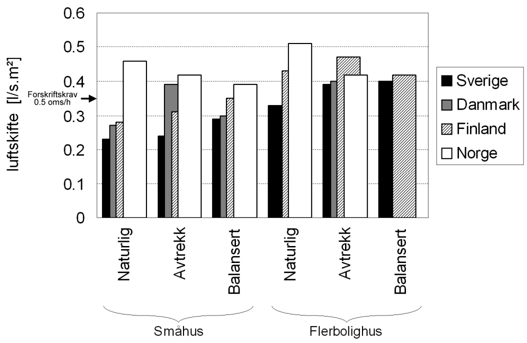


Figure 3: Mean ventilation rate depending on type of dwelling (*småhus*=houses; *flerbolighus*=apartments) and ventilation system (*avtrekk*=mechanical exhaust). Data is combined from various field studies in 4 Nordic countries. Mean building age differs between the studies. The Norwegian data is combined from 5 field studies, and shows a different trend from the other countries, possibly due to dissimilar measurement method. 0.35 (ℓ/s)/m² is equivalent to 0.5 air changes per hour (ach).

Ventilation rates: These field studies show that the natural- and mechanical exhaust often does not provide the ventilation rate required in the regulations, while balanced ventilation provides, on average, the highest air change of the three ventilation strategies. Exhaust systems do not seem to be adapted to today's more airtight construction.

The largest data set in Figure 3 is the Swedish ELIB study (Norlén 1993), an IAQ survey in 3300 dwellings, of which measurements were carried out in a third of the dwellings . Air change in 86% of houses and 50% of the apartments was below 0.5 ach. Newer houses with natural ventilation had particularly poor ventilation. In the largest of the five Norwegian data sets included in Figure 3 (Øie 1998), 36% of 343 homes with exhaust ventilation were under-ventilated. In Blom's study (1995), 70% of the 25 measured the homes, with mainly exhaust ventilation, were under-ventilated. In the Norwegian dataset the houses with balanced ventilation appear less well ventilated than natural- and mechanical extract — this is likely due to being more airtight buildings.

Other Norwegian studies on risk factors for the development of allergy or Black Magic Dust show increased prevalence in poorly ventilated buildings together with chemical exposure factors (phthalates, particles and SVOC). For this reason, Norway may consider tightening the building regulations to 0.6 ach/h for new airtight dwellings (EN 15251 Class II) in 2015.

Bedroom ventilation: In Norwegian homes, warm duvets are popular, so many people open their bedroom windows at night to let in cool air, even if there are fresh air vents. This might explain the pattern in Figure 3, which indicates more intensive window airing in naturally ventilated Norwegian buildings. Window airing has downsides, such as outdoor noise, no air filtration, heating costs, risk of burglary, and not least cold drafts, especially for infants who tend to kick off their duvet at night. Approximately 50% of Norwegians therefore choose to sleep with closed windows in the winter in homes with mechanical extract. In Blom's study (1995), bedroom CO_2 concentrations rose to 2500 ~ 3000 ppm with closed windows in houses with mechanical extract.

Even when there is no difference in ventilation flow rate, exhaust systems do not to give the same IEQ as balanced systems. Occupants often close vents to prevent cold drafts. This is often observed in multifamily housing (Figure 4a). Another issue with exhaust ventilation is that the stack-effect in winter causes less fresh air to enter vents in the upper floors than the lower floors. Moreover, opening a bedroom window can 'puncture' the house, significantly reducing the underpressure and flow rate in the other bedrooms, even when the air transfer devices between rooms are properly sized (unlike Figure 4b). A study by Schild (1998) shows that in order to guarantee proper ventilation of bedrooms more than 75% of the year, a normal exhaust ventilation system must have a flow rate of 1 ach. This leads to a larger heating costs, and increased underpressure, which exasperates draft discomfort, seepage of radon, and return smoke in fireplaces. These problems could be alleviated by using sophisticated vents with constant flow for pressure differences of as little as 1 Pa, such as exist in The Netherlands. These products are not established in Norway.

(a) Vents are often closed or blocked to prevent cold drafts ant reduce heating costs.

(b) Air transfer is often undersized or nonexistent. It is not part of the HVAC contract.

Figure 4: Examples problems with exhaust ventilation. Fotos © SINTEF

Duct system and filtering: People are happier with the IAQ in dwellings with spiro-ducts compared to flexible ducts (χ^2-test: P=99.5% in Schild 2003). This may be because rigid smooth circular ducts do not restrict flow, or soil as quickly as flexible ducts (Figure 5).

One drawback with balanced ventilation is dust deposition in the air intake and supply ducts, leading to a gradual degradation in IAQ. Supply air ducts should be inspected every 5~10 years and cleaned when needed. This is not being done in dwellings. Duct fitters do not yet make duct systems inspection-friendly in accordance with EN 12097. In reality, the problem may not be so large. From Schild's analysis of different aged systems (2003), there is possibly a slight trend of gradually poorer air quality over time, but there is not enough data for statistical analysis. There are firms that specialize in duct cleaning, and it is even possible for homeowners to clean their own ducts with a special vacuum brush fitting.

Figure 5: Flexible ducts have higher flow resistance, and can be crushed or punctured. They probably also soil quicker, and more difficult to clean.
Foto © ABS cleaning Ltd

Another explanation for the duct cleanliness and high satisfaction with IAQ is filtering. 48% of the systems had bag filters (e.g. Figure 1a), which do not clog up as fast as pleated panel filters. Standard supply filter quality is EU7, and EU5 for exhaust. Households are surprisingly diligent to change filters (33% twice yearly, 42% yearly, 11% every other year, and those who had not changed the filter yet had mainly brand new systems). Just as many respondents see the need to clean the inside of the HRV unit, though they do it less frequently, supposedly because the filters keep it clean. Maybe the survey has a disproportionately large number of allergy sufferers who were highly motivated to fit HRV to improve IAQ (as opposed to being forced by building regulations).

Noise

Ventilation noise is often regarded as the Achilles' heel of balanced ventilation. Most households in the study (Schild 2003) have in fact no noise problem; 28% react to some noise in the bedroom/living room, and 2% find it very disturbing. The systems with spiro-ducts had the least noise problems. The situation has probably further improved since 2007, when the SFP requirement was introduced. Noise can be easily prevented by proper design of the duct system and terminals, and use of silencers. Moreover, designers should be aware that the threshold for *noise comfort* is actually 5 dB(A) lower than the *legal limit* in the building regulations. Vibration is another annoyance: The study showed that HRV units placed above the kitchen hood and in occupied rooms cause the biggest noise complaints. The HRV unit should generally be located in an easily accessible unoccupied room, but not on a wall adjacent to a bedroom.

One issue with exhaust ventilation is traffic noise and lack of filtering. The Norwegian Public Roads Administration (*Vegvesenet*) are therefore obliged to fit balanced ventilation in some existing houses that are located near to roads that have experienced a huge growth in traffic.

Thermal comfort and draft

As expected, in the study, only 2% complain of thermal discomfort due to drafts. It is a misconception that heat recovery contributes to overheating in summer. All HRV units have a "summer mode" with zero heat recovery, ideally with automatic control based on supply air temperature, such as rotation speed of rotary heat exchangers. Overheating is rather caused by insufficient passive cooling such as solar shading. Having said that, we have seen cases where south-facing air inlets or insufficient thermal insulation of supply ductwork in multifamily dwellings has contributed to thermal discomfort in summer (Eriksen et al, 2006).

Moisture damage

Many Nordic field studies (Norlén 1993; Holme 2010) have shown significantly higher humidity and mould growth in homes with natural ventilation than homes with mechanical exhaust ventilation, which in turn were more humid than houses with balanced ventilation.

(a) Mold in a naturally ventilated dwelling with poor ventilation. Foto © SINTEF

(b) Rot in roof construction due to poor design and inadequate ventilation. Foto © Finn AS

Figure 6: Examples of moisture damage where ventilation has played a role.

Dry air and air quality

Complaints of dry air are not uncommon in winter, when indoor relative humidity drops with the outdoor air moisture content. Good ventilation and few people in a large house may give periods with less than 25% RH inside in cold spells, causing cracking of woodwork, dry skin and eyes etc. However, health risks associated with high RH are significantly more substantial and well documented. Humidification of homes is therefore avoided, apart from exceptional medical reasons (e.g. infants with croup). A gentler solution is to use a heat exchanger with moisture recovery. The study (Schild 2003) showed that standard aluminium rotor heat exchangers are ideal for this purpose in dwellings, as they recover moisture only by condensation, i.e. only in the coldest weather, and lead to significantly fewer complaints about both dryness and dissatisfaction with air quality.

Energy use

Actual energy savings with heat recovery

In the 2003 study, homes with high efficiency heat exchangers (80%) used 10~15% less total energy than homes with traditional cross-flow plate heat exchangers, and about 20~25% less than homes with air/air heat pumps. No houses had contraflow plate heat exchangers. The reason for poor heat pump performance was a combination of low power, low COP, and limited exhaust temperature (0 °C), and the fact that they may also be used for cooling. The newest heat pumps today perform better.

However, comparison between the energy consumption in HRV houses and national statistics on energy use in homes shows only a small reduction (Schild 2003). This is because housing with balanced ventilation have generally higher air exchange rate. Many of the houses with HRV may have had poor airtightness, further increasing the air exchange.

Ventilation habits

A quarter of respondents open their bedroom window every night (half of which open the window more than 5 cm). This is fewer than for houses with exhaust ventilation. Nevertheless, HRV seems to be keeping bedrooms warmer than necessary. Cool air is feels fresher. Analysis of energy consumption data showed that regular window airing in HRV-houses increased total energy consumption by between 0% and 20%.

Usability and reliability

Usability

80% of households claim that their HRV system is easy to maintain. Similarly, 87% believe that the manual is satisfactory or very good. However, 24% of households said that the unit's control panel lacked useful indicators or that it was complex. Manufacturers have since worked to improve the user-friendliness of their HRV control panels.

Reliability

On average, there is 6.8% risk that a HRV unit with heat exchanger needing maintenance in any year. This is almost three times as much as for mechanical exhaust systems (Blom 1995), but much better than exhaust heat pump systems. The reported 'technical problems' are in fact largely normal wear-and-tear on electromechanical components, such as electronic relays and fan motors. This is in line with a previous study of 15 housing companies (84,000 homes) in Europe (Månsson 2002), which found that the average probability of complaints related to ventilation is 7.5% per property per year for residential units (2.5% for central units). There is a marked difference in reliability between the different manufacturers. The most reliable HRV models are least as reliable as for simple mechanical exhaust systems.

PRODUCTS

The market shift from natural ventilation to mechanical ventilation, and then HRV, has given Norway's HVAC trade sufficient time to learn good practices and improve its products.

Norwegian law requires that building products be documented according to relevant national or international standards. There is a national scheme for technical approvals and certified testing. However, third party documentation is not mandatory for HVAC products, so manufacturers may document products in their own laboratories, and present data on their own websites. HVAC product documentation generally follows European standards, and so in theory should be harmonized between the various manufacturers. Examples are duct components (sizes: EN 1506, and airtightness: EN 12237), silencers (insertion loss: EN-ISO 7235), air terminals (pressure drop and acoustics: EN-ISO 7235), and filter classes (EN 779).

Air handling units are documented for flow capacity, fan power, acoustics and heat recovery efficiency. The documentation for central units follows EN 13779 / EN 13053, while single-dwelling units follow EN 13141-7. The main suppliers of central units have Eurovent certified dimensioning software. Eurovent is now starting similar certification of dwelling units. Since Norwegian law does not require *certified* documentation, there have been some cases where very inaccurate performance data has been claimed for SFP and heat recovery efficiency. Another issue is that EN 13141-7 measures the supply temperature to after the fan, which gives a 'temperature ratio' that is 10% higher than the true efficiency of the heat exchanger. To solve this issue, the national EP-calculation standard NS 3031 gives a simple equation to estimate the true heat exchanger efficiency, akin to the value documented for large air handling units with EN 308. The main Norwegian suppliers of dwelling units use this correction, so that documented heat recovery efficiency is harmonized for all unit sizes. The There is presently no international standard that describes a test method to test the effective defrost temperature. NS 3031 gives a table with default values for different types of heat exchanger and building. This issue will have to be tackled in revisions of CEN standards.

Suppliers have a very significant responsibility in ensuring the quality a HRV system during its entire operating life. The tightened regulations, and competition between Nordic manufacturers of HRV units, has motivated them to work to improve the quality of their products and services. Some examples are given here.

- Modern units have EC fans to reduce SFP and noise. These fans also have electronics to allow easier commissioning and continuous control of the flow rate.
- To reduce noise, more voluminous casing with thicker walls are used.
- Detailed installation manuals.
- The units have front-opening doors to give access for cleaning and filter changing.
- Modern HRV units have better control panels, enabling easier control of settings, and commissioning (display of supply temperature, fan power, in-built measurement of flow rate, and heat recovery efficiency). Some have a filter alarm.

- Rotary heat exchangers have become standard in small residential HRV units. These have many benefits over plate traditional heat exchangers. They can achieve high efficiency without frost problems, and avoid the need to connect condensate drain to the unit. Condensate drains are a risk factor in their own right, as the water in the "U"-bend/trap tends to dry out during the summer, allowing sewage gases to seep into the air supply. Furthermore, rotors have continuous speed control to prevent indoor overheating, and moisture recovery during the coldest winters, thus mitigating the problem of dry indoor air.
- EU7 supply filters are a minimum industry standard. This keeps the supply ducts clean from dust. The exhaust air also has a good filter to prevent soiling of the heat exchanger. These filters should ideally be EU5 or better.
- Some suppliers have air filter subscription schemes, whereby they send new filters in the post to the homeowner, once or twice a year.
- The major HRV suppliers are well aware of the importance of quality in fitting and commissioning. They have an optional 'design service' and use duct design & acoustics software such as MagiCAD, and can provide tailor-made installation drawings and parts lists. The suppliers can also cooperate with, or recommend, professional contractors.
- Many suppliers have partner companies that can offer a servicing contract.

DESIGN

There is no dedicated education scheme or certification specific to designers of residential ventilation systems. However, the industry has built up a competence-base. The research foundation SINTEF has various design guides and handbooks on residential ventilation.

Small residential HRV systems tend to be designed by the suppliers themselves. The design staff will generally have a technical college or bachelor engineering degree, and have additional training in duct system design and CAD software.

Larger systems, in apartment buildings, tend to be designed by HVAC consultant engineers. Such consultants have a university engineering degree, with additional in-house training in general HVAC design. HVAC engineers can apply for chartered status ("RIV").

Irrespective of who has designed or fitted the ventilation system. Experience has shown us that poor installations are a result of the following problems:

- Small profit margins in the building trade, selecting solutions to just comply with the absolute minimum standards in the building regulations, and poor commissioning.
- Lack of pressure-drop or acoustics calculations, or poor predictive accuracy of the software, maybe combined with misleading product documentation.

INSTALLATION & COMMISSIONING

Fitting contractors

Fitting and commissioning of ventilation systems in houses is normally done by small specialized contractors, while other much larger HVAC contractors large buildings (including apartments). In some cases, house building contractors (i.e. carpenters) have installed ventilation system themselves to cut costs. Such systems are invariably improperly designed, fitted and commissioned.

There is no training scheme specific for residential ventilation fitters. Ventilation fitters are in a joint guild, www.vbl.no, together with tinners (e.g. metal facadework). To achieve a certificate of apprenticeship (*fagbrev*) takes 4 years, of which 2 years are at college and the last 2 are paid work as an apprentice. This training focuses more on metalwork and fitting, not so much on ventilation theory or commissioning. Each province in Norway has an administrative guild's office (*lokal opplæringskontor*) that follows up companies with apprentices. The industry is aware of the need to establish a specialized apprenticeship or ventilation fitters, where they can learn more relevant theory on electronics, controls, balancing etc., needed to commission modern variable air volume (VAV) systems.

Commissioning

Commissioning generally involves balancing flow rates such that all terminals are within 10% of design flow rate. The balancing protocol should in theory be part of the hand-over documentation together with the instruction manuals for the HRV. Noise is rarely checked.

Installation errors and inadequate commissioning are common in residential ventilation (Blom 1995). Poor commissioning goes undiscovered because third party checks are not required for residential ventilation. This problem also effected the quality of mechanical exhaust systems.

Large contractors have good resources to provide training for their staff, either in-house or external. The research foundation SINTEF runs a two-day general training course in commissioning of ventilation systems, two-to-four times a year. The course participants get hands-on-experience with balancing and instruments for measurement of airflow and fan-power. The course compendium acts as a trade norm. There is also a popular 1-day course on VAV commissioning, and one on ventilation noise which much fewer attendees.

For VAV systems, the lack of competence mentioned above means that often two contractors have to be used to, one to fit the duct system and one for controls. This causes significant coordination problems and pulverization of responsibility during commissioning. Partnering or multidisciplinary contractors should therefore be used more in future.

MAINTENANCE

HRV systems need more servicing than natural ventilation or mechanical exhaust systems, in order to operate optimally. Regular servicing must involve changing filters at least once a year depending on the outdoor air quality (at least just after the pollen season). It is best practice to replace filters at fixed intervals, instead of waiting for the filter pressure drop to rise above a threshold limit. Other servicing tasks are cleaning the inside of the HRV unit, and inspecting the duct system to check whether they need cleaning. Such servicing is the sole responsibility of the home owner. HRV units are supplied together with a user manual that describes servicing tasks. The manual should be stored inside the HRV cabinet.

Relatively few people in the study (Schild 2003) had a filter subscription. Not all vendors have this service. Most households contact the vendor each time to order new filters. Only 5% have a service contract, but 32% would consider such an arrangement. No one who had such an agreement commented that they are unhappy with it.

Servicing technician is a full-time 2-year education at vocational college for people who have a certificate of apprenticeship. It covers topics such as electronics, ventilation and piping.

INSPECTIONS

There is a national obligatory EPBD inspection scheme for any ventilation systems with a heating or cooling power of over 12 kW. Although this exceeds the requirements in Article 8 & 9 in EPBD, it excludes residential ventilation systems. The scheme is largely an extension of earlier voluntary inspection regimes for boilers etc. by qualified service personnel.

BUILDING ENERGY PERFORMANCE ASSESSMENT CREDITS AND PENALTIES FOR SYSTEM QUALITY

The EP-certificate is affected by the quality of the following factors: SFP, heat recovery efficiency including defrost, air change rate, and airtightness of the building facade only.

CONCLUSION

Balanced ventilation is a mature technology that is now standard in all new Norwegian buildings. It has benefits in terms of IAQ, comfort, and energy use. However there remain challanges (Table 1). Experience tells us that voluntary measures are largely ineffective; so quality improvements should be introduced though the building regulations.

Topic	Major causes of quality problems	Existing quality schemes or incentives
Product	Product documentation	National norm for documentation; Eurovent certification; Ecodesign requirements
Design	Ventilation noise (no acoustic calculations conducted). Poor kitchen hood performance. Odour	Design literature; Building regulations (SFP requirement has reduced noise, considering to increase ventilation requirement to 0.6 ach)
Installation, Commissioning	No third-party checking of flow rates and noise	Training courses on duct system commissioning, Discussing possibility of third party spot checks
Maintenance	Air filter not replaced, due to owner ignorance. HRV and duct system not cleaned	Filter subscription and/or service contract (e.g. paid by rent to housing cooperative)

Table 1: 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.

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QUALITY OF VENTILATION SYSTEMS IN RESIDENTIAL BUILDINGS:

STATUS AND PERSPECTIVES IN POLAND

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ABSTRACT

Housing in Poland is dominated by natural ventilation - passive stack ventilation. That follows from the building tradition. The fact that passive stack ventilation is commonly used does not mean that its performance is correct. Shortcomings of natural ventilation and increasing awareness of investors have led in the recent years to noticeable trend to adopt more and more often mechanical ventilation. In addition, for the quality of mechanical ventilation in residential buildings standardization of regulations and technical requirements concerning system designing and making is necessary.

KEYWORDS
Residential ventilation, passive stack ventilation, mechanical ventilation, heat recovery, guidelines for ventilation systems.

INTRODUCTION
The number of apartments built in Poland exceeds 100 000 annually and depends on the economic situation. As the number of new apartments remains still insufficient in comparison with social expectations, and the size of apartments already in use is smaller than the average size in developed European countries, it is foreseeable that housing will continue to develop for at least the nearest ten or fifteen years.

In recent years approximately the same number of apartments was built in single family buildings as in multi-family ones. It is worth noting that almost 100% of single family houses are erected by individual investors. Single family homes built by developers have a marginal significance.

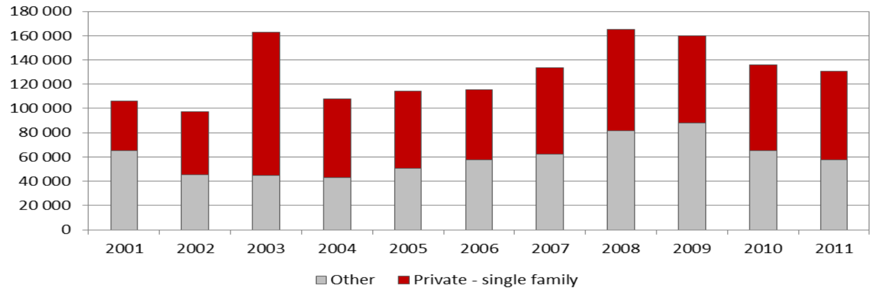

Figure 1: Participation of single family housing in overall housing activities.

More than 60% of all apartments in use in Poland are in multi-family buildings. Multi-family houses, especially those built in large towns, are mostly large, multi-story buildings.

RESIDENTIAL VENTILATION MARKET

Regardless of the kind of residential building natural, passive stack ventilation is the dominating type of ventilation. This follows from the building tradition and habits of both investors and architects.

Data on ventilation systems used are not dealt with in the housing statistics. However, it can be assumed that mechanically ventilated buildings make no more than 5-10% of residential buildings in use.

Passive stack ventilation adopted in residential buildings is functioning according to the following pattern:
a) natural supply of fresh air from the outside through leaks in the building envelope or through appropriate air inlets installed in the outer partitions (windows or walls),
b) natural removal of interior air via exhaust ducts located in strictly defined spaces of living quarters.
Until the year 2000 individual or common exhaust ducts were used. Where common ducts were used apartments on every second story were connected to one duct. That was allowed by the building standards. After the year 2000 ventilation standards were amended and now each apartment has to be provided with its own exhaust ducts.
Passive stack ventilation may be adopted in buildings of up to 9 stories. For higher buildings mechanical, exhaust or supply/exhaust ventilation is obligatory. In practice mechanical exhaust ventilation has almost solely been adopted.

Mechanical exhaust ventilation adopted in residential buildings is functioning according to the following pattern:
a) natural supply of fresh air from the outside through leaks in the building envelope or through appropriate air inlets installed in the outer partitions (windows or walls),
b) mechanical removal of interior air via exhaust ducts located in strictly defined spaces of living quarters.
Interior air is removed through common exhaust ducts, to which rooms serving the same purpose, located on different stories, are connected. Exhaust fans are mounted on the building roof (common fans for the respective risers). Adoption of individual exhaust fans for the respective rooms is another solution. Mechanical exhaust ventilation is mainly used in multi-family houses.

Exhaust points, both for natural and mechanical ventilation, have to be placed at least in the kitchen, bathroom and toilet (if separate). There also exist other detailed recommendations concerning location of exhaust ducts.

Supply of fresh air from the outside has to be provided at least to rooms. The amount and manner of fresh air supply are specified in regulations. Generally, the amount of air flowing into an apartment has to be equal to the amount of air removed from it. At the same time it is necessary to ensure that each person foreseen in the building design as a permanent dweller be provided with at least 20 m^3 of fresh air per hour. For many years the issue of air supply has been presented in regulations in an insufficiently clear manner, which has led to the common occurrence of a problem of improper (too low) inflow of air to buildings, and hence to common appearance of natural ventilation disturbances. The regulations were revised in 2009 and he rules of ventilation air supply were set down very clearly. An obligation to install vents in windows or outer walls, both for natural and mechanical exhaust ventilation, was introduced.

Simultaneous use of natural and mechanical ventilation in ventilated rooms is prohibited.

Mechanical supply/exhaust ventilation in housing, when chosen, has almost exclusively been adopted in single family buildings. Systems of that type are always fitted with air handling units with heat recovery. Some buildings are additionally equipped with ground heat exchangers. Mechanically ventilated are all spaces of single family houses except for boiler rooms, which have natural ventilation. This is a requirement specified in the building code.

It is the architect – the main designer of the building – who decides in the majority of cases which system of ventilation to choose. Also the investor, who accepts the solution proposed by the architect, plays an important part in the decision process. It follows from investigations carried out by the Polish Ventilation Association that for most designs of single family buildings natural ventilation is proposed by the architects whereas the clients do not consider using another type of ventilation. Most often due to the lack of knowledge. Mechanical ventilation is chosen by those individual investors who have by themselves sought modern technologies. As much as 70% of investors deciding to adopt mechanical ventilation have made that decision on their own, without architect's participation. Supply/exhaust ventilation with heat recovery has been chosen, mainly with the intention to reduce heating costs for the building.

The statistics, as mentioned above, of mechanical ventilation use (5-10%) concerned all of the existing buildings. However, the recent 3-5 years brought a significant change of situation. The share of mechanical ventilation in multi-family buildings has been increasing at a fairly high rate. The Polish Ventilation Association has estimations showing that in the recent 2-3 years about 50% of multi-family buildings built were fitted with mechanical ventilation. That mainly concerns buildings erected in large towns. It should be added that a considerable part of residential buildings erected in large towns has underground garages. Separate regulations require that garages of that type be mechanically ventilated even if natural ventilation is used in the living quarters.

The situation in the single family housing is different. About 10 years ago almost 100% of single family houses were naturally ventilated. Even though in the recent years the share of buildings provided with mechanical ventilation has been increasing, they still constitute a margin. It can be estimated that about 5-10% of single family buildings are being fitted with mechanical ventilation. However, investors' interest has been increasing from one year to another. Many investors are interested in adoption of technologies that lead to reduction of building heating costs. Thus the market potential is very high. A special program for supporting energy saving building will start in 2013. It will be possible for investors to get extra money to installments loans for energy saving housing. Adoption of mechanical ventilation systems with heat recovery is one of requirements to be met in order to qualify for such a money.

All buildings erected in Poland have to be designed and built in accordance with the detailed building code. The code requires that continuously working ventilation be ensured in each building. Regulations that specify ventilation requirements refer to ventilation standards and present a number of detailed requirements concerning the manner of ventilation system

constructing. Thus the regulations are a blend of goals to be reached on the one side and detailed technical guidelines on the other side.
The minimum volumetric flow rate of ventilation air defined for a specific type of apartment is the principal factor determining the required ventilation of residential buildings. The minimum volumetric flow rate of ventilation air for an apartment is determined as a sum of flow rates of air removed from the respective spaces [1]:
- kitchen with external window, equipped with a gas or coal cooker - 70 m^3/h,
- kitchen with external window, equipped with an electric cooker - 30 m^3/h in an apartment for up to 3 persons, 50 m^3/h in an apartment for more than 3 persons,
- kitchen without an external window fitted with an electric cooker - 50 m^3/h,
- bathroom with or without a toilet - 50 m^3/h,
- separate toilet - 30 m^3/h,
- auxiliary room without a window - 15 m^3/h.

At the same time an assumption is adopted that the amount of air flowing into the apartment has to be equal to the amount of air removed from it. It is also necessary to ensure that each person foreseen as an apartment user be provided with at least 20 m^3 of fresh air per hour.

A procedure of building acceptance has to be carried out prior to putting it into use. In the case of mechanical ventilation measurements of system capacity are made and compliance with the requirements and design is assessed. Fire dampers installed at the inlets to common exhaust ducts are subject to additional inspection.

Acceptance of passive stack ventilation, whose performance varies depending on the season of the year and external conditions, poses a problem. Hence in practice acceptance proceedings for passive stack ventilation are limited to checking the cross-sectional area of exhaust ducts, checking if they are passable and air-tight, and also assessing the construction of chimneys above the roof surface. The capacity is measured in a simplified way. As a result it sometimes happens that buildings/apartments where ventilation performs incorrectly are favorably assessed. Improper delivery of fresh air to the building and the height of exhaust ducts too small for reaching the required capacity are some of more frequently found failures.
Buildings are in their lifetime subject to obligatory annual technical inspections, which also cover the ventilation system operation. As in the case of system acceptance proceedings inspection of passive stack ventilation is limited to checking if exhaust ducts are passable and air-tight, and making approximate measurements of capacity.

One can hazard a guess, based on signals coming from the building market, that a significant part of buildings provided with natural ventilation is plagued with permanent ventilation performance failures. That, as well as the increasing awareness of developers may be the reason for the increase of the share of buildings fitted with mechanical ventilation. Rise of the interest in mechanical ventilation might also occur if the building regulations were better organized and ordered objective enforcement of ventilation performance quality.

PRODUCTS

All products and devices used in the building industry, including also those used for construction of ventilation systems, are subject to standard requirements in effect for sale of products. These are requirements complying with the European Union law. No additional restrictions and requirements are imposed on products and equipment for ventilation. Regulations do not prevent introducing on the Polish market products used in other EU countries.

As ventilation systems in residential buildings are built out of the same products and devices as systems installed in other buildings, no special system for certification of products for housing is used in Poland. Properties of respective products are tested by the manufacturers and the manufacturers declare the conformity of the products they deliver with the test results. Reliable manufacturers care about testing product features in accordance with the European Standards. Designers and contractors have access to catalog data of the manufacturers and may use them as a basis for comparing product parameters.
A requirement to be satisfied by air inlets are an example of requirement absent in the European Standard but imposed in Poland on products for the Polish market. The Polish Standard [1] requires that air inlet allows a flow of a specific amount of air. Air inlet for a natural ventilation system should ensure a flow at a rate between 20 and 50 m^3/h, while those for mechanical exhaust ventilation - a flow at a rate between 15 and 30 m^3/h. Full closing of air inlet must not be possible.
Despite the fact that manufacturers test their products a straight comparison of the test results is not always possible. Air handling units with heat recovery designed for use in residential buildings are an example of product for which divergent data are provided by manufacturers/suppliers. Fairly often the designers, contractors and investors get from the suppliers data of marketing nature. The heat recovery efficiency is the main parameter of the air handling units and it is that parameter which is sometimes stated in inconsistent manner.

DESIGN

The design process of ventilation in residential buildings involves the engineering knowledge and recommendations given in standards and the building code. No special guidelines, repeatable schemes and recommended technologies for designing ventilation in residential buildings exist. Requirements concerning the ventilation intensity are specified in the appropriate Polish Standard, which also gives many instructions about the way of constructing a natural ventilation. General requirements presented in said standard are also accepted for mechanical ventilation, whereas construction details for mechanical ventilation system are described in a separate standard dealing with that type of ventilation.
In Poland it is an architect who is the chief designer of a building, responsible also for the designs in the respective trades. In practice, mechanical ventilation designs are made by specialized designers, who choose together with the architect a ventilation system for the building concerned and afterwards make detailed calculations and designs for system details. The designers should have special design licenses. Persons without design license can neither make designs on their own nor supervise investment execution. Owing to such division of tasks in the design process as well as the licensing requirement designs of ventilation systems are in general correct. However, fairly frequently the system designer representing the architect only prepares a design concept which covers selection of basic components of the system. A detailed technical design of system components is made by the company responsible for investment execution. A shortcoming of that solution is the fact that the contractor making the system tends to minimize the investment costs, as he is paid for his work a lump sum. As a result it happens that equipment and materials preliminarily proposed in the design concept are replaced by their cheaper equivalents. Such replacement is not always favorable from the technical point of view. Acting under the cost minimizing pressure reflects in the quality of system components used.

Passive stack ventilation is designed by architects. The term “designing” with reference to passive stack ventilation is somewhat an exaggeration. On the one hand, it is difficult to reliably design a system which has to operate under variable conditions deciding on its performance. Ventilation ducts chosen for natural ventilation in Polish climatic conditions have to operate in conditions extremely varying throughout the year. The external temperature in winter is for months below 0°C, and in many days it is below –10°C. On the other hand, the external temperature in summer exceeds +20°C. Obviously, under such conditions passive stack ventilation may not operate stably according to some assumptions. Moreover, in many cases natural ventilation does not perform according to expectations.

The role of the architect in passive stack ventilation designing process reduces in the majority of cases to choosing appropriate locations of exhaust ducts and designing chimneys above the roof slope. Ducts of 14x14cm cross section and height resulting from the building geometry prevail. Regrettably, differentiation of duct cross sections and choosing duct heights in order to satisfy the capacity requirements is seldom adopted. Consequently, some ducts do not reach the capacity assumed as they are too short. That mainly concerns apartments located on the highest 2-3 stories. That problem arises in the majority of multi-family buildings in which flat roofs predominate. At the same time apartments on the lower stories of multi-story buildings, having very high exhaust ducts, are often excessively ventilated, which leads to needless energy losses in winter.

System designers and architects have an obligation to be members Professional Chambers. The chambers oblige their members to self education, however the topics are not specified. For that reason the Polish Ventilation Association attempts to cooperate with the Professional Chambers, proposing to include problems related to ventilation in the training topics. The Association is active in performing trainings, both for Chamber members and for professionals outside the Chamber training scheme.

INSTALLATION

It may not be said that natural ventilation is made by system contractors. Building of ventilation ducts is done by the building contractor and consists in making exhaust ducts and installing external air inlets in windows. Usually air inlets are installed by window manufacturers.

It is the engineer acting as a construction manager who is responsible for supervising the making of passive stack ventilation. He represents the chief building contractor or the investor and is responsible for investment execution in accordance with the design. The construction manager must possess a special license for construction management.

Mechanical ventilation systems are assembled by specialized system contractors. The working teams should be managed by persons possessing special licenses. Small investments, such as single family houses, are often managed by persons without licenses, and the construction manager supervises their work and the system construction. On larger construction sites the company responsible for ventilation system construction employs most often persons possessing licenses for managing such work.

The contractors do their work using the technical knowledge based on practical experience and diverse recommendations and guidelines. The recommendations and guidelines are given by various institutions, research institutes and ventilation technology suppliers. No publication exists which would contain a complete set of guidelines for ventilation system assembling. Various guidelines available on the market have no force of law. Therefore divergences in assessment of the quality of work in that domain are not infrequent.

Guidelines for ventilation systems with heat recovery for single family houses, worked out by the Polish Ventilation Association are an example of trade guidelines.

In 2012 the technical group “Ventilation in single family houses” (working in the structure of the Polish Ventilation Association) worked out “Guidelines for ventilation systems with heat recovery (recuperation system) for single family houses”.
The guidelines have been worked out based on legal regulations and many years practical experience of companies involved in that work. Having in mind first of all a greater comfort for the future occupants of the houses guidelines recommends in some cases solutions that exceed the minimum requirements set forth in legal regulations. The guidelines have been drawn up mainly for two groups of users: contractors involved in mounting ventilation systems in single family houses and investors. They form a kind of common communication platform for contractors and investors, on the one side orienting the contractors to specific goals, and on the other side providing the investors with the knowledge of what should they definitely require from contractors to get a fully effective system and properly invest the means foreseen for its purchase.
The guidelines not follow any countries when formulating the guiding principle. This is an original idea adapted to the specificity of the Polish market.

The requirements for the ventilation intensity are shown in the table below [2].

	Standard values (minimum)		**Recommended values**
	Flow rate of supply air	**Flow rate of exhaust air**	**Air change rate or air flow rate**
	A		**B**
	Use the value from column A or B, whichever is higher.		
Type and intended use of space	**[m^3/h]**	**[m^3/h]**	**[1/h]**
Closed kitchen, fitted with a gas cooker	70	70	2
Open kitchen, fitted with a gas cooker	-	70	2
Open kitchen, fitted with an electric cooker	-	50	2
Bathroom	-	50	2-3
Lavatory (without a bathtub or shower cabin)	-	30	2-3
Vestibule and auxiliary rooms, such as cloakroom, pantry	-	15	1
Staircase / hall	-	-	50 m^3/h minimum
Laundry / drying room / recreation rooms	-	-	2
Living quarters: room, living room, bedroom, study	20 m^3/h/person	20 m^3/h/person	1
Attic (when its intended use is unspecified)	-	-	1
Garage, boiler room, technical room, utility room	gravity ventilation or other type of ventilation in accordance with detailed regulations		

Table 1. The requirements for the ventilation intensity based on the „Guidelines for ventilation systems with heat recovery (recuperation system) for single family houses” [2]

In specifying the intensity of ventilation for individual spaces the “Guidelines…” recommend choosing the higher value from columns A and B.

COMMISSIONING

Commissioning and acceptance of ventilation systems in residential buildings concern in principle mechanical ventilation only. Contractor representatives start the system, adjust it in order to reach the design parameters in all apartments and make measurements for the respective components of the system. The measurements are made in accordance with the requirements of a relevant European standard.

The system capacity measurements form the basis for drawing up an acceptance act, which is a necessary part of the construction documentation, required for issuing an operating permit.

Acceptance of passive stack ventilation is done by chimney sweep foremen, who check the basic elements: cross section dimensions of exhaust ducts, and duct passability and air tightness. The acceptance by chimney sweep ought to include a duct capacity measurement, but such a measurement may only be made in accordance with Polish Standard guidelines in some months of the year, when the external temperature is equal to +12°C. In other cases the measurement may only provide an approximate assessment of the duct capacity. Such a way of conducting passive stack ventilation acceptance makes an objective assessment of the ventilation performance practically impossible.

INSPECTIONS AND MAINTENANCE

Owners and managers of residential buildings are obliged by law to maintain the buildings in the technical condition ensuring the safety of people and property. According to requirements imposed by regulations the ventilation should ensure an effective exchange of air conforming to the design parameters. While in the case of mechanical ventilation keeping to conditions assumed in the design is possible, meeting that requirement by natural ventilation can be in practice neither verified nor enforced.

The regulations require that the owners and managers carry out regular inspections of the technical condition of the buildings. For ventilation systems annual inspection of exhaust duct passability and air tightness and checks of ventilation grille passability is required. These inspection may be conducted by chimney sweep foremen. According to the regulations mechanical ventilation should be inspected by system construction specialists.

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

In Polish climatic conditions the energy needed for ventilation air heating up takes a significant share of the building energy balance. The consumption of energy for ventilation purposes is taken into account in the calculation procedure adopted for energy certification (according to EPBD). The ventilation air flow rate plays the principal role in these calculations. One of two solutions is adopted – either the air flow rate conforming to the regulation requirements or the actual flow rate resulting from design parameters and building operation program. For passive stack ventilation and mechanical exhaust ventilation with a fixed capacity the flow rate according to the standard is adopted, while for mechanical ventilation with heat recovery or with a variable capacity the flow rate is corrected, taking into account, among others, the heat recovery, use of a ground heat exchanger and temporary changes of the capacity. Additionally, air infiltration is taken into consideration. An appropriate value of a correction factor is adopted depending on if an air tightness test was conducted or not for the building. As air tightness test are only sporadically carried out, the infiltration is assumed mostly as a derivative of the volume ventilated.

Excessive infiltration and thus excessive ventilation leads to large energy losses. Residents wanting to reduce the ventilation often block the exhausting ducts, and thus result in a low quality of indoor climate.

Topic	Major causes of quality problems	Existing quality schemes or incentives
Product	No clear technical information on air handling units with heat recovery.	No
Design	Improper designing of passive stack ventilation by architects.	Yes / PN-83/B-03430/Az; Building Code
Installation	Incorrect air flow, incorrect location of valves, no respect for the noise reduction (mechanical ventilation).	Yes / PN-83/B-03430/Az3; PN 73 B-03431; Guidelines for ventilation systems with heat recovery (recuperation system) for single family houses
Commissioning	No clear rules of commissioning passive stack ventilation.	No
Maintenance	Acceptance for incorrect function of passive stack ventilation.	Yes / Regulation of the Minister
Inspections	Acceptance for incorrect function of passive stack ventilation.	Yes / Regulation of the Minister

Table 2: 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.

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

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1. INTRODUCTION

1.1 The actual situation of buildings constructed before 1989

The structure and quality of ventilation systems depend on the type of the building (single or multifamily residential), the number of levels built, year of construction and the thermal rehabilitation stage.

The multifamily buildings built before 1989 were endowed with natural ventilation in individual shafts (Fig.1 – up to 4-storey buildings) or common shafts (fig.1b - over 4 floors) built of masonry or precast concrete. Balancing air intake was achieved by infiltration through the carpentry windows due to the difference of pressure between inside and outside air or wind pressure. In some cases ventilation cowls were used on the roof to improve air circulation using wind energy.

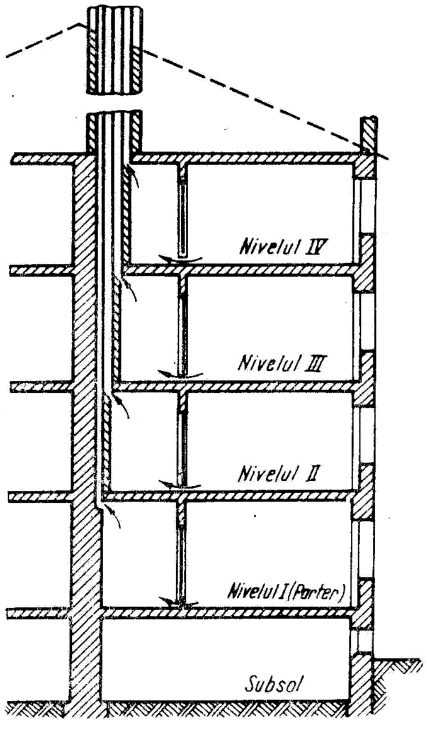

Fig. 1a

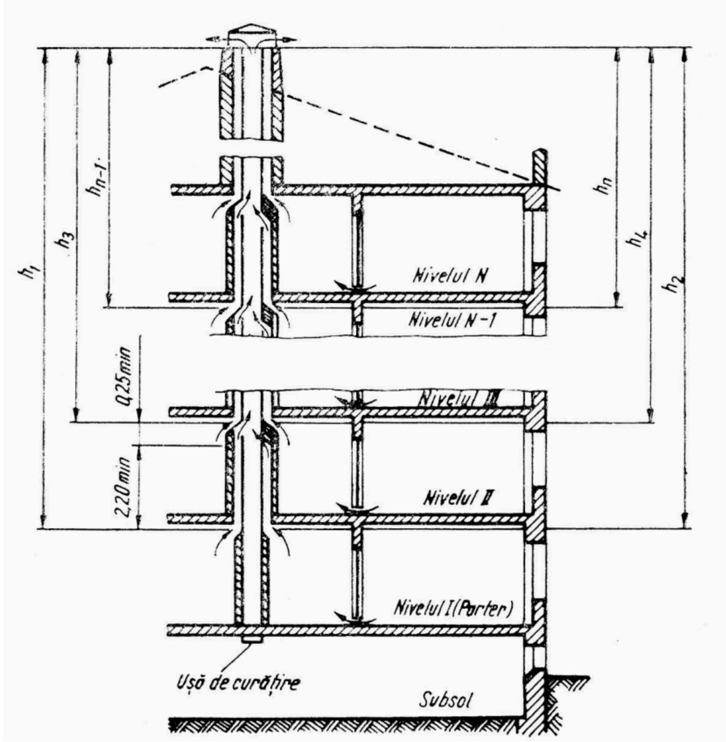

fig 1b

These ventilation systems connecting bathrooms, kitchens, food pantries and rooms without exterior windows generally had an acceptable operating mode.

Since 1989 with the first wave of real estate and the changing of owners, although the law provided that any inner change has to be authorized, without any real check inside the apartments, common shafts were often dismantled for refurbishing and enlarging the interior space, with repercussions over ventilation system by suppressing of course all lower floors.

The situation became even worse after individual or collective actions changing the window's carpentry, their higher sealing suppressing the balancing air flow infiltration. Thus, the only real ventilating system remaining is opening the windows, air quality is moderate or low depending on the frequency, duration and degree of the opening. Due to high humidity and thermal bridges mold appeared in several rooms.

In some cases, to "improve" the air quality, local wall-fans were connected to the common shaft without solving the problem of balancing air intake, unwillingly showing no interest over the repercussions of this action over the other users connected to the same ventilation shaft.

1.2 The situation of the new residential buildings

In the multi-storey new buildings, according to the project were provided general mechanical exhaust systems in bathrooms without exterior windows, balancing air intake grilles being mounted in kitchen's or room's outside walls, but most often air intake compensation was omitted, this aspect being the fault of the designer or the fault of the beneficiary in order to reduce costs. Air is usually exhausted by small wall-fans connected to a common ventilation shaft, switching on the fans being made in the same time with the lighting switch on, with a short delay before stopping at lightning switch off.

Kitchens were generally provided with exhaust hoods, most often without duct connection working in recirculation mode, so that the necessary ventilation rate is not achieved. There are also cases in which ventilation shafts were created to connect only exhaust hoods from kitchens.

For single or multi-family houses generally simplified ventilation systems were used, based on the pattern of multistage buildings: mechanical exhaust ventilation for bathrooms without outside windows (rarely) and ventilation hoods for kitchens connected to ducts penetrating the outer wall.

On some projects, but rather seldom, plate heat recovery were used to exhaust the warm air from the bathrooms and supplying preheated fresh air in the main rooms. There are also some residential projects (mostly single family houses) provided with air handling units for ventilation and air conditioning with a mixing room for fresh air intake ratio.

In conclusion the market for residential ventilation systems could become slightly higher by informing the owners and raising the awareness of users on the causes of low quality air in rooms and the high energy consumptions, showing the solutions on the market to improve those problems. However the actual increase is moderate due to the global economic situation.

2. PRODUCTS ON THE ROMANIAN MARKET

The market is still dominated by the small wall-fans (Fig. 2) which apparently solves the problem of ventilation in bathroom spaces. However gaining more and more ground the heat recovery waked the user's awareness on energy saving due to the gas and thermal energy rising costs.

Although less known at the moment, the hygro-controlled ventilation grilles (fig. 4, 5) have been introduced to Romanian market and promoted by manufacturers and installers of window's carpentry. The hygro-controlled grills are installed on the window's frame allowing the balance air flow to pass the grills more or less depending on the inside air humidity.

In order to be introduced to the Romanian market, the products should be CE certified, or (alternatively) the supplier must obtain a Technical Agreement with a validity of two years.

The interest of producers is focused mainly on the public buildings, trade and offices where there is a greater demand on the market and the value of equipment offered for these buildings makes them obviously more commercially attractive. Therefore frequently product presentations and trainings are organized, providing guidance on equipment selection for planners, investors and technical staff assembly companies.

So the interest of providers in residential ventilation equipment is still relatively low because of the low demand of investments.

Fig.2 Small wall-fan

Fig.3 Heat recovery for the residential

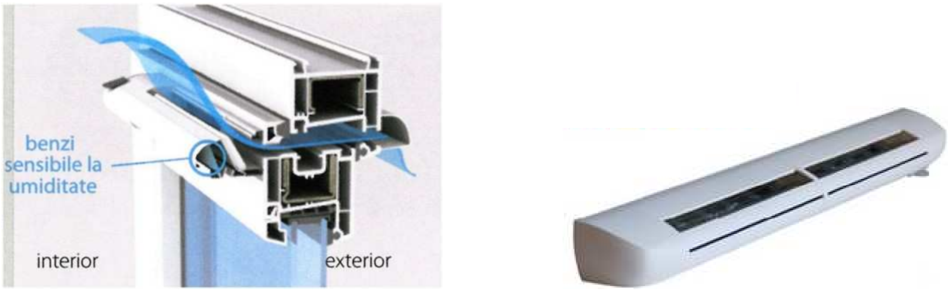

Fig.4 Hygro-controlled ventilation grills

Fig.5 Hygro-controlled ventilation grills

3. DESIGN

The Installation's Engineering Manual in Romania includes chapters for practitioners and students devoted to deepening the basis of ventilation systems for both buildings and industrial applications. Further training of specialists in this field is usually done through practice and self study in the absence of specific training courses for residential area.

3.1 Design hypothesis (extract from the Romanian Norm I5-2010)

3.1.1. The organised ventilation of residential buildings should be general and constant at least during the period of the year when the outside temperature does not allow frequent opening of windows.

3.1.2. Airflow must be achieved by supplying air into the main rooms (living room, bedroom, office) and exhaust to the service rooms (kitchen, bathrooms, toilets).

Indoor air quality class	**Short description**
IDA 1	High quality of indoor air
IDA 2	Medium quality of indoor air
IDA 3	Poor quality of indoor air
IDA 4	Low quality of indoor air

Table 1. Indoor air quality classes (SR EN 13779:2007)

3.1.3. Ventilation systems, mechanical or natural flow shall be sized so that the exhausted air flow rates shown in the Table 2 must be achieved in winter average weather conditions. These flow rates must be provided by the system, simultaneously or individually.

The number of main rooms	Exhaust air flow rates m3/h				
	Kitchen	Bath or showers in the same room or not with the toilets	Additional shower	Toilets	
				Single-	Multi-
1	75	15	-	-	-
2	90	15	15	15	15
3	105	30	15	15	15
4	120	30	15	30	15
5 or more	135	30	15	30	15

Table 2. Exhaust air flow rates for ventilation of residential buildings

3.1.4 Exhausted air flow rates should be balanced by fresh air through intake devices and permeability of the facade.

3.1.5. Each main room must have at least one air intake device that satisfy the requirements of 3.1.3.

3.1.6. Through individual devices the air flow rates as defined by the Art. 3.1.3. can be reduced to the values given in Table 3 only if the total exhaust flow and the reduced flow from the kitchen at least equals that values.

	The number of main rooms						
	1	2	3	4	5	6	7
Total exhaust flow – minimum values [m3/h]	35	60	75	90	105	120	135
Kitchen reduced flow – minimum values [m3/h]	20	30	45	45	45	45	45

Table 3. Minimum air flow rates for the ventilation of residential buildings

3.2 Legislation milestones and general considerations on the design

Through the legislation milestones regarding the residential building's ventilation we can mention the following, without enumerate them all:

- Law nr. 10/1995 regarding the quality in the building field of activity
- Law nr.372/2005 regarding building energy performance requirements
- I5-2010, Romanian Norm for designing, mounting and operating the ventilation and air conditioned systems
- MC 001/2006 Calculations of the energy consumption performances for the buildings
- SR EN ISO 7730:2006, Ergonomics of the thermal environment - Analytical determination and interpretation of the thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria
- SR CR 1752:2002, Ventilation systems for the building. Design criteria for indoor thermal comfort

The responsible authority for the verification of compliance with the laws and regulations in force is the State Inspectorate in Constructions - ISC. The I5 Romanian norm provisions are mandatory except those specified as "recommended". However, the residential area check of the ISC is often limited to the structure, the installations being often neglected.

Therefore, due to desire to limit the investment's costs, beneficiaries typically do not order a Ventilation project and often avoid to install such a system or usually resort to the "experience" of the contractor who generally install a kitchen hood or a wall-fan in the bathroom neglecting balancing air intake, energy recovery, required air flow and the pattern of air circulation in the rooms. This results ventilation systems which do not meet the requirements, have high consumption of heat and electricity and poor air quality in rooms.

Currently the regulation for certifying of specialists in the field of design, installing and operation of building's equipment and plants is only a draft legislation, developed and proposed by the Romanian Association of Building Services Engineers that will also certify and control the activity of specialists. This is under discussions with relevant authorities in Romania, in order to build an effective and reliable quality assurance system.

4. INSTALLATION

Generally, for residential buildings there are no technical details (qualification schemes) that specify how these ventilation systems should be installed. There are also no dedicated training courses for the installers. They are performing according to the installation instructions provided by the supplier in the delivery package or according to the manufacturer's own website (if it exists). Generally the equipments are delivered with an operating manual and a warranty certificate; these are usually the only documentation that the owner has, in the absence of a technical project.

The first step needed to develop a coherent system to ensure the qualification of the building workforce relating to energy efficient technologies (including ventilation systems) is to adopt and implement the National Qualification Framework. This action, together with other priority measures, is proposed in the Qualification Roadmap to 2020, which is under development and endorsement in the BUILD UP Skills Romania (ROBUST) project. The existing occupational standards for HVAC installers need to be revised and adapted to the need of implementing energy efficiency technologies, and adequate qualification schemes are needed. Nevertheless, minimum requirements on efficient ventilation systems, qualification of installers and quality assurance for the execution of works are mandatory actions to ensure the uptake of thermal refurbishment programs and to support the implementation of nearly zero energy buildings in Romania.

As it was stated above there is a legislative initiative that regards the authorization of the specialists that are entitled to install these ventilation systems.

As the market demand increases it will increase the interests of producers and suppliers to promote new products and to train the specialists to install these ventilation systems.

The above mentioned legislation applies to the design, montage and operation of ventilation systems in residential buildings.

The grants awarded is generally for thermal rehabilitation of buildings, where the accent is on upgrading the thermal protection of the envelope and leaving most of the times aside the ventilation system which is assumed to work properly under normal conditions.

5. COMMISSIONING

Commissioning is performed by the installer or in some situations the supplier's technical staff if there are strict conditions for high-value equipment warranty. Generally, for residential buildings there are no technical details that specify how these ventilation systems should be commissioned, the instructions are provided by the supplier in the delivery package or according to the manufacturer's own website. Most times there is no technical project for the ventilation system and the commissioning procedures depend on the operator experience and the existence of internal working procedures based on an international best practice guidance on commissioning.

6. MAINTENANCE

Maintenance of ventilation systems in residential buildings remains generally in charge of the beneficiaries who often do not give much importance to the system, only when it is out of order or it presents operating noticeable abnormalities. Currently, for residential buildings there are signed very rarely maintenance contracts with companies specialized in maintenance on ventilation systems and it is preferred to benefit of the services of these companies only in case of defects.

7. THE INSPECTIONS

Although the State Inspectorate in Constructions (ISC) has in its field of activity the control of building and its installation’s behavior during the entire life of the building, in the residential area the check of ventilation systems is often neglected.

8. THE INFLUENCE OF THE VENTILATION SYSTEM’S QUALITY ON THE CREDITS AND PENALITIES REGARDING ENERGY PERFORMANCE CERTIFICATE OF THE BUILDING

Thermal rehabilitation of residential buildings is implemented by several financing programs and the general conditions are regulated by the Law Nr.372/2005 Energy performance of buildings (as mentioned before) and the methodology for calculating the energy performance of buildings Mc 001/2006;

Lack of ventilation system in a building is punishable by a lower rate, but the energy class is not affected because the ventilation airflow is usually considered the "normal operating conditions", even these conditions are not really achieved.

9. CONCLUSION

In the residential area the ventilation systems market is still undeveloped due to low demand and poor check made by state authorities (State Inspectorate in Constructions - ISC) despite of very stringent regulations in the field. Lack of interest from producers in the residential area and the lack of training courses for designers, installers and technical staff for commissioning and maintenance results in decreasing the quality of systems designed and built and the poor indoor air quality with indirect repercussions on the energy savings and human health.

The legal framework in buildings needs to be updated in order to introduce an adequate definition ‘nearly zero energy buildings’ in Romania [7] and to provide minimum requirements for residential ventilation (adequate to very energy efficient buildings, e.g. mechanical ventilation with heat recovery). Nevertheless, the development of large impact and long-lasting qualification schemes for HVAC installers and introducing quality check requirements for airtightness and efficiency of ventilation systems for high performance residential buildings are actions which need to be defined today and implemented in short and medium term in order to ensure an effective implementation of EU vision regarding the energy performance evolution of building stock in Romania.

Subject	Major causes of quality problems	Quality of existing systems or initiatives
1	**2**	**3**
Market products	Lack of market demand	Yes – certificate CE, AT technical agreements
Design	Lack of training programs and effective check of the ISC at the design stage	Yes – law nr.10, norm I5 / 2010
Installations	Lack of training programs and effective check of the ISC at the installation stage	Yes – law nr.10, normative I5 / 2010
Commissioning	Lack of training and procedures for commissioning based on recommendations of good practice guide lines	Yes – law nr.10, normative I5 / 2010. Qualification schemes to be developed according to BUILD UP Skills Roadmap to 2020.
Maintenance	Lack of beneficiaries interest	Yes – law nr.10, normative I5 / 2010
Inspections	Poor ISC check	Yes – law nr.10, normative I5 / 2010

Table 4: Summary of problems observed in terms of residential ventilation systems quality and the schemes that have been implemented or are being developed to overcome these problems.

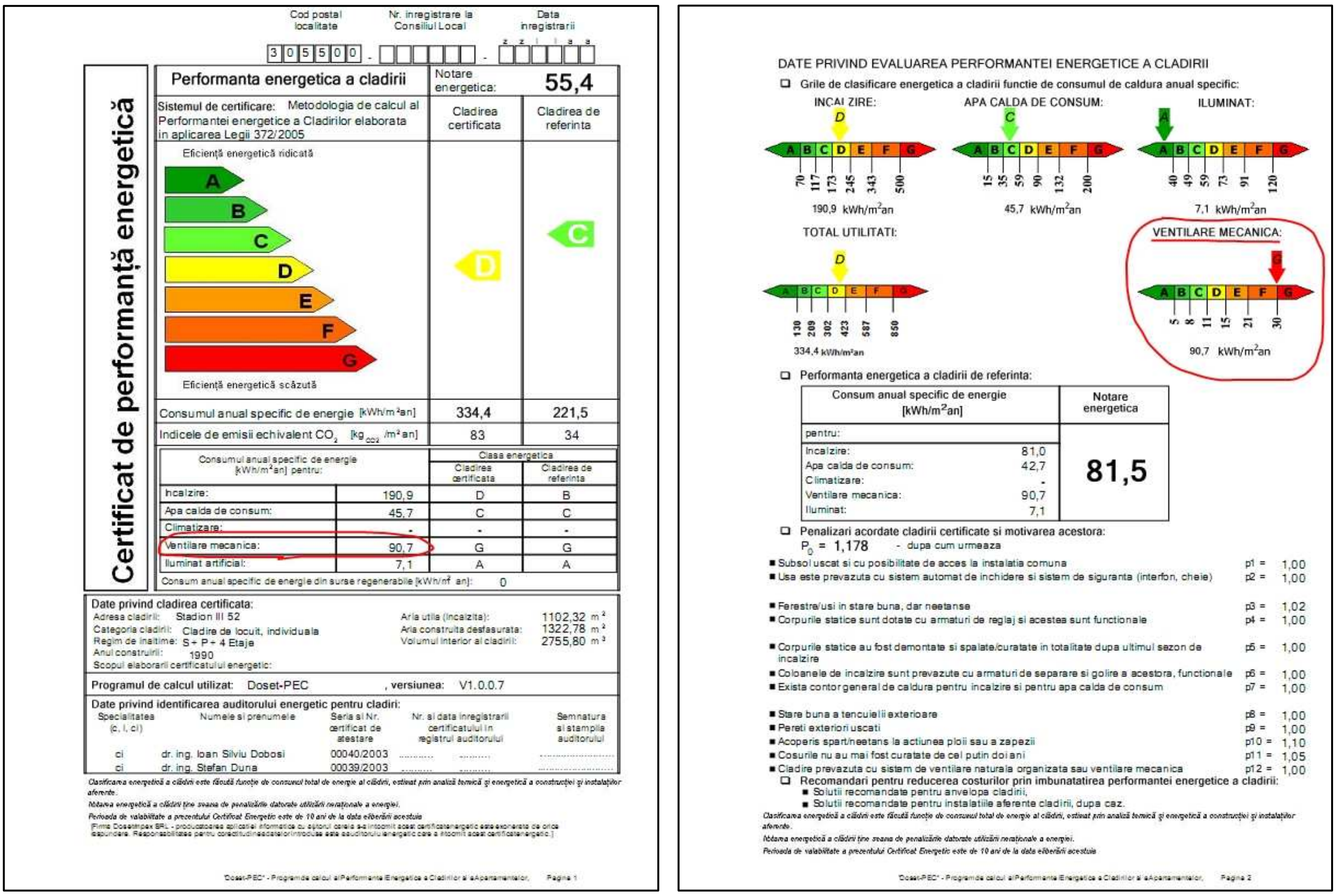

Fig.6 Building's Energy Performance Certificate

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

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ABSTRACT
There are about 4.4 million dwellings in Sweden divided in rather equal parts between multi-family buildings (2.4 million) and single-family houses (2 million). 40% of the dwellings in multi-family buildings are privately owned (as all the single-family houses) while the rest (60 % of the dwellings) are rented. The age of the buildings, which of course influences the installed type of ventilation system, varies – 65 % was built before 1970, 14 % during 1971-1980, 8 % 1981-1990, 7 % 1991-2000, and 6 % after 2000.
The first oil crises 1972 lead often to a change of systems from natural ventilation to mechanical extract; increasing energy prices and a trend toward sustainability have further lead to balanced ventilation systems with heat recovery or mechanical extract system with heat pump.
Another problem with ventilation of dwellings has also been identified – the impact of radon exposure on humans. There are two facts making this a major problem – up until 1975 it was very common in Sweden to use radon emitting (blue) light concrete (“Alum Shale Concrete”) as a construction material. This coincided with a period with extensive building activities – between 1965 and 1975 one million dwellings were built in Sweden. Almost half a million homes in Sweden are so badly affected by radon that they need to be sanitized.
During the 1980-ies several studies reported health problems from emissions in badly ventilated dwellings. This resulted in in a new Swedish law requiring compulsory inspection of ventilation systems – the OVK commissioning system that is described in the paper.
The quality of ventilation systems in Sweden is also governed by another unique scheme – AMA - General Material and Workmanship Specifications. It has been in use since 1950 and is a tool for the customer to specify his demands on a new building and its installations.

KEYWORDS
AMA, OVK, Residential ventilation, Radon

RESIDENTIAL VENTILATION MARKET
There are about 4.4 million dwellings in Sweden divided in rather equal parts between multi-family buildings (2.4 million) and single-family houses (2 million). 40% of the dwellings in multi-family buildings are privately owned (as all the single-family houses) while the rest are rented. The age of the buildings, which of course influences the installed type of ventilation system, varies – 65 % was built before 1970, 14 % during 1971-1980, 8 % 1981-1990, 7 % 1991-2000, and 6 % after 2000.
The first global oil crises 1972 with rapidly increasing energy prices often led to a change of systems from oil-based to electric heating and from natural ventilation to mechanical extract. The vast majority of residential buildings in Sweden built before 1970 were equipped with natural supply and exhaust (“S-system”). As a follow-up of the first global oil crisis 1972-73, with rationing and rapidly increasing energy prices, the Swedish authorities raised the demands on thermal insulation and tightness for new buildings in order to reduce the oil import.

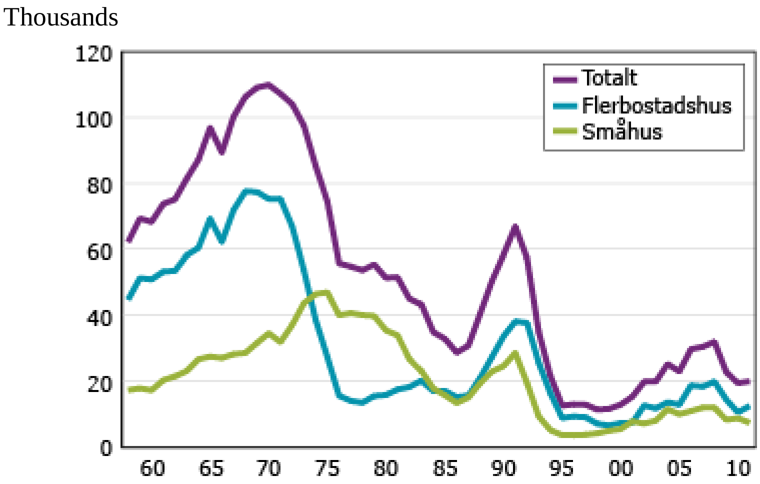

Figure 1 - Number of annually finished dwellings in Sweden (**totally**, **multi-family houses** and **single-family houses**).

Consequently also older buildings were renovated as the energy prices rose rapidly. Often the renovation however only dealt with the building shell, improving its tightness and thermal insulation, but not changing the ventilation from the now found inadequate S-system (tighter façades and lower room temperatures reduced the airflows considerably).

At the second half of the 1970's new buildings and a large majority of the renovated older buildings were equipped with natural supply and mechanical exhaust ("F-system").
Most of the buildings from the 1980's and 1990's have ventilation systems with fans and ductwork. Mostly used are F-system but also FT-system are quite common especially in buildings where the supply air intake thus can be located away from street noise, dust and gases. A trend toward sustainability in the last decade has further led to a more common use of balanced ventilation systems with heat recovery (FTX-system) or mechanical extract systems with heat pump, either for heating tap water and/or water for radiator heating (FVP).
Most of the buildings from 2000 and onwards are of these two types, FTX-system or FVP-system. For new villas a FVP-system has more or less become a standard solution in Sweden.

Type of system	Swedish Designation	Distribution %
no ventilation system	-	**0**
natural supply and exhaust	**S-system**	**40**
natural supply and mechanical exhaust	**F-system**	**40**
natural supply and mechanical exhaust with heat pump	**FVP-system**	**8**
mechanical supply and natural exhaust	(T-system)	**0**
mechanical supply and exhaust without heat recovery	**FT-system**	**4**
mechanical supply and exhaust with heat recovery	**FTX-system**	**8**

Table 1 - Distribution of ventilation system types in Swedish residential buildings

Legal requirements regarding residential buildings
In Sweden residential buildings are required to provide an acceptable air quality. To fulfill this requirement follows that it is a legal obligation to install ventilation systems (mechanical or natural) in new multi-family houses.

The Swedish national environmental legislation states that: “In the year 2020 all buildings shall be healthy and have a good indoor environment”. One of the intermediate goals within the frame of good indoor climate is that: “All buildings where people stay often or during a longer time shall 2015 at the latest have been proven to have a functioning ventilation system”.

Two Swedish authorities regulate residential ventilation – Boverket (The National Board of Housing, Building and Planning) in “BBR” mainly for new installations and Socialstyrelsen (The National Board of Health and Welfare) for the use of existing installations. (A third authority, The Swedish Work Environment Authority, issues ventilation demands on places of work). There are few authority prescriptive rules expressed in numbers or quantities; the few exceptions cover e.g. minimum O.A. supply (0.35 l/s, m^2), draught levels (max 0.15 m/s in winter), temperatures and noise levels. The main demands are instead given as performance requirements such as (from BBR):
“Good air quality shall be obtained in rooms where people stay more than temporarily, the air quality requirement shall be based on the use of the building, the air shall not include any substances that are harmful or result in bad smell. In dwelling-houses where the ventilation airflow can be controlled locally it can be lowered (from 0.35) to 0.10 l/s, m^2 when no one is present.”

High radon levels in many Swedish dwellings
Up until 1975 it was very common in Sweden to use (blue) light concrete (“Alum Shale Concrete”) as a construction material. It had many advantages – good insulation properties, light and easy to use – but it had one, at that time not identified major disadvantage – it was radon emitting. The common use of this material coincided with a period with extensive building activities in Sweden – between 1965 and 1975 one million dwellings were built.
Another factor that increased the radon problem is that about ten percent of all multi-family and single-family houses in Sweden are built on high radon ground. Estimation shows that out of the ca. 3,000 people that die from lung cancer every year in Sweden, ca. 500 die as a result of excess levels of radon in homes. Almost half a million homes in Sweden are so badly affected by radon that they need to be sanitized.

The Swedish Radiation Protection Agency, SSI, estimates that about 150,000 homes have a radiation level higher than 400 Bq/m^3 compared to the threshold value of 200 Bq/m^3. A similar amount of homes probably have a radon level between 200 and 400 Bq/m^3 which also is far too high. In 2003 the national program for radon decontamination of single homes set aside a fund to help home owners to finance improved ventilation (15,000 SEK per home) but the interest from the home owners to apply for this subsidy has been very low!

OVK - Compulsory inspection of ventilation systems
Many Swedish and Nordic studies during the 1980’s showed that defective and badly maintained ventilation systems and insufficient airflows was a main reason for sick buildings. One large study showed e.g. that this resulted in health problems for children at home, in schools and day nurseries.

Type of building and ventilation system	Inspection intervals
Day nurseries, schools and hospitals	3 years
Block of flats and offices with FT-ventilation	3 years
Block of flats and offices with F-ventilation	6 years
Block of flats and offices with S-ventilation	6 years
One and two dwelling-houses with FT-ventilation	only first inspection (new buildings)

Table 2 - OVK inspection intervals for different buildings and ventilation systems

This resulted in a new Swedish law 1991 requiring compulsory inspection of ventilation systems – the OVK commissioning system – with aim to control and improve the function of ventilation installations. The ordinance requires that the ventilation in most types of buildings has to be controlled before_the installations are taken into operation and then regularly_at recurrent inspections. Boverket is responsible for this control system and for nation-wide authorization of the inspectors while local authorities control the observance of the law locally and report the result to Boverket.

The inspector records the inspection. The result of the OVK inspection, the certificate, is given to the owner with a copy sent to the local authority. A copy of the certificate shall be posted in full view in the building by the owner, e.g. at the building entrance or staircase. The Local building committee shall supervise that the OVK rules are followed and that the inspectors work correctly. If the owner doesn't follow the rules or if he is not rectifying reported deficiencies the committee can order the owner to take actions, otherwise he will be punished economically.

PRODUCTS

Information and field campaigns of ventilation system quality in residential buildings

Awareness of the importance of having a well-functioning domestic ventilation system has increased in the latter years due to information from authorities, trade organizations and companies. Manufacturers of residential ventilation systems are aware of the role that they can play in and use these arguments when they market their products and systems individually or collectively through their trade organisation Svensk Ventilation.

Authorities (those mentioned above plus the Swedish Energy Agency) and trade organizations (e.g. Svensk Ventilation) are involved in spreading information in books and brochures about the necessity of having both a good air quality and a low energy use in villas and dwellings.

Residential ventilation product characteristics – requirements and certification

Swedish ventilation products from larger manufacturers are normally classified according to Eurovent's requirements. Parallel with that Swedish ventilation products manufacturers are normally, in their catalogues and otherwise, referring to the quality requirements stated in HVAC AMA. AMA (**A**llmän **M**aterial och **A**rbetsbeskrivning) meaning "General Material and Workmanship Specifications" has been in use in Sweden since 1950. AMA is a tool for the employer (developer/future proprietor) to specify his demands on the new building and its installations in the building specification.

Figure 2 - Part of the AMA and RA books in the 1998 edition – VVS means HVAC

Designers refer to the AMA quality requirements regarding product characteristics in their building specifications for HVAC systems and the installers (have to) follow these product and system requirements. The demands in AMA are specified in measurable units and in such a way that the tenderers and contractors understand them and are able to calculate a price for their commitments.
The AMA requirements are based on accepted demands – these are regularly updated in accordance with technology development and (LCC)-costs. Experience from the more than 60 year old use of AMA has shown that it has led to a substantially raised quality level.

HVAC AMA covers e.g. quality of all components, air handling units and ductwork but also how these requirements will be tested and reported during commissioning. Another book in the AMA family, AF AMA, covers administrative requirements such as guarantee periods and commissioning.

COMMISSIONING

Before a new ventilation installation is taken into operation it is thus controlled in two separate ways:
(1) The OVK compulsory inspection for ventilation control as described above.
The first inspection controls that the function and quality of the system corresponds to valid directions, that the system does not contain pollutants that can be spread in the building, that instructions are easily available for the maintenance personnel, and the system functions in the way intended (i.e. designed).

(2) The commissioning controls that the installation is performed according to the contract conditions as required in specifications and drawings.
It also includes e.g. control of protocols of measured airflows, testing of ductwork tightness and measuring of noise levels as well as checking that the system and component quality fulfils AMA requirements and that the installation operates as prescribed.
There are standard rules for commissioning in the Swedish General Contract Conditions "AB" used in combination with AMA – this is the normal procedure to control that the two contract partners, the contractor and the owner, have lived up to the contract conditions: the inspector compares the actual installation with the contract, building specification, protocols, other relevant documents and as-built drawings. Discrepancies and faults are noted in the commissioning protocol and shall be attended to within a prescribed time.

MAINTENANCE

AMA also specifies if, and how, the contractor shall deliver manuals for maintenance of the ventilation system.

The installer will either deliver either complete “tailor-made” maintenance manuals covering all components in the ventilation system to the owner (if this AMA requirement is included in the contract); or otherwise they will provide only the background material (documents from the manufacturers covering maintenance of components, spare parts etc.) to the owner who then appoints a consultant to write the manual. Even though it is not mandatory, each of the larger manufacturers has own manuals for the installation and maintenance of their residential ventilation equipment.

There are no detailed maintenance standards or guidelines but the maintenance of residential ventilation systems normally includes a visual inspection of the installation, changing of filters, control of dampers and vibrations and abnormal noise from fans and pumps, need of ductwork cleaning, checking of belt drives and heat exchangers, etc.

The maintenance is normally done by a company specialized in HVAC maintenance but larger real-estate companies often have own maintenance personnel. There are no dedicated education schemes for residential ventilation systems maintenance but this normally forms a part of training courses for maintenance personnel in general; these courses are normally focusing on more complicated installations.
The contract will sometimes also include an additional AMA requirement covering training program for the owner’s maintenance personnel.

INSTALLATION

Design standards and guidelines

Residential ventilation is to some extent included in the guide part (RA) of HVAC AMA but also in guide lines issued by Energi- och miljötekniska föreningen, (the Swedish HVAC Association - member of REHVA). When applicable AMA refers to Swedish standards and EU-norms (e.g. filter classes and testing). There are a few authority prescriptive rules as reported above; most of these are expressed as performance requirements. In some cases Boverket refers to AMA demands and to guidelines (R1) issued by the Swedish HVAC Association (air quality and thermal climate).

Training schemes for designers and installers

Both designers and installers are well aware of the role they can play in raising the quality of the installations. There are several continuation courses at different levels and with different aims, e.g. Methods for measurement and adjustment of ventilation systems.

A new scheme that will lead to certification of ventilation installers has just been started. The certification scheme is organized by the trade organization for ductwork manufacturers. The requirement for getting a certificate is normally that the installer follows a comprehensive course and succeeds in the examination. The examination requirements cover a wide area, e.g. manufacturing installation methods, measuring and adjusting airflows, noise attenuation, reducing energy use, contract conditions and AMA, etc. The certification covers the person and not the company (even though the company normally covers the cost for certification of their employed installers).

INSPECTIONS

The mandatory inspection of residential ventilation systems according to the OVK systems has been described above. There are no other inspection standards or guidelines covering inspection. Beside the OVK inspection the owner often contracts a specialized service provider that regularly checks all the installations and takes necessary actions; these actions are often based on statistics (e.g. filter change every year). He will also be aware of the wear and tear of the installation with increasing age of the systems and be able to provide the owner with recommendations on renovations and replacement of worn components.

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

EP calculation and the quality of ventilation system

The quality of ventilation system is not a factor taken into account at the EP calculation - but it should be! Quality factors that should influence the result could e.g. be results from measured air leakage based on required tightness class and area, measured airflow rates, in-use factors, measured efficacy of heat recovery system, use of certified installers, etc.

Credits or penalties linked to the quality of residential ventilation systems

My opinion is that FTX-systems (supply and extract systems with high efficiency heat recovery) should have credit. The same also applies to FVP-systems (extract systems with heat pump). Natural ventilation or extract systems with direct air intake from the outside, e.g. at street level, should be penalized at least in downtown areas and cold regions. The supply air is normally not filtered (or passing by inferior filters) which is detrimental to acceptable air quality. In wintertime the system often results in complains of cold draught and thus unacceptable thermal indoor climate. The system also lacks possibility to recover heat which increases the energy use, i.e. this is an unsustainable and non-sustainable solution.
Systems having bad, or no, maintenance should be penalized. The difficulty is probably how this can be controlled.

Topic	Major causes of quality problems	Existing quality schemes or incentives
Product	Designed and specified products are changed to other than specified	Follow the specification or be aware of the consequences, AMA
Design	Design for simple installing, maintenance and future exchange	None in use
Installation	Lacking quality control; specifications are not followed	Control and measure that you have got what you pay for, AMA
Commissioning	Too fast and not detailed	AB and AMA; OVK
Maintenance	It is missing; manuals missing, unskilled personnel	Control and plan the maintenance and need of renovation and exchange
Inspections	There aren't any; supervision instruments are missing	Regular OVK inspections, energy auditing, authority demands on functioning ventilation

Table 3 - Summary of problems observed regarding quality of residential systems and schemes that are implemented or are under development to overcome these problems.

CONCLUSION

The quality of ventilation systems in residential buildings must correspond to reasonable demands on air quality, thermal climate, low noise levels, low energy use and sustainability.

In order to make this possible we need to supervise the quality of systems and components, check the workmanship during installation, control by commissioning that the installations comply with the intended design. Inadequate quality and performance found should be changed and rectified to fulfil the contract conditions and our demands.

But a well performed work is not worth the money invested in the system unless it is taken care of by a well-suited maintenance that makes it possible to maintain the quality during the coming years.

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QUALITY OF VENTILATION SYSTEMS IN RESIDENTIAL BUILDINGS: STATUS AND PERSPECTIVES IN THE UK

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ABSTRACT
All new homes currently being built within the UK incorporate some type of ventilation system, the majority of which are of the mechanical fan type. Installation, inspection and commissioning of these systems is covered by Building Regulations, and there are training schemes in-place which allow individuals to become Competent Persons to undertake these tasks. Data appertaining to the installation, inspection and commissioning process is lodged with the Building Control Body as evidence of compliance to the Regulations.
As part of the portfolio of services offered to house builders, BSRIA has undertaken an extensive testing programme on ventilation over recent years, and this shows that 95% of everything initially evaluated failed to meet the requirements of the Building Regulations with some installations having a number of failure modes.

KEYWORDS
Ventilation, fans, dwellings, residential housing, UK Building Regulations, Approved Document Part F, Mechanical Heat Recovery, MVHR, MEV, SAP Appendix Q,

INTRODUCTION
The UK housing sector can be considered as being well developed with approximately 135,000 dwellings being completed in 2011, and the majority of these containing mechanical ventilation systems. The market is dominated by large-scale national developers with less than 50 companies building more than 500 homes each annually. The self-build market in the UK currently contributes about 12 per cent of total new housing and this includes those who appoint a builder to do the construction work on a plot of land. In 2011 there was an estimated 27.4 million dwellings in the UK, with 17.4 million privately owned, 4.7 million privately rented, 2.7 million rented from housing authorities with the remainder rented from local authorities. [1]

Statistics relating to the stock profile are produced on a regular basis by the UK National Statistics Office, and are published by the Department for Communities and Local Government (DCLG). Data can be extracted from these statistics in many forms, for example approximately one-in-five dwellings in the UK were built before 1919, with the majority of all dwellings (80%) houses or bungalows, and 95% of dwellings were of traditional masonry or timber construction; the majority of these were cavity brick/block. Non-traditional construction is often seen as synonymous with social housing but half of these dwellings are actually in the private sector. These statistics do not contain any data relating to ventilation systems installed into the dwelling, so the size of the market is ascertained by independent research such as that conducted by BSRIA Worldwide Market Intelligence Centre who obtain data from manufacturers and suppliers through robust survey techniques.

RESIDENTIAL VENTILATION MARKET

To comply with the current UK Building Regulations all new domestic homes are built with some type of ventilation system incorporated. These ventilation systems are categorised into four groups as defined in Table 1.

Type	Description	Background ventilation	Comments
System 1	Background ventilators and intermittent extract fans including single room heat recovery ventilators	Yes	Size as per tables in Regulations based on floor area and number of bedrooms
System 2	Passive stack ventilation (PSV)	Yes	As above
System 3	Continuous mechanical extract (MEV): centralised and de-centralised	Yes and No	Size as per tables in Regulations or if air permeability >5m^3/(m.^{2}) none is required
System 4	Continuous mechanical supply and extract with heat recovery (MVHR): centralised and single room	No	

Table 1: Ventilation system type description

It should be noted that other types of ventilation systems such as Demand Control Ventilation (DCV) are allowed to be used within the UK, but the design must be shown to achieve certain criteria such as the removal rate of moisture and other indoor air pollutants to the satisfaction of the Building Control Body.

Within the UK there are separate Building Regulations published in England and Wales, Scotland and Northern Ireland along with their second tier guidance documents. In general terms these are all similar in nature, and for the purposes of this paper the Regulations in each of the regions should all be considered as being equal.
Approved Document F which came into force in October 2010 deals with the functional requirements for ventilation systems. It states “There shall be adequate means of ventilation provided for people in the building” and “Fixed systems for mechanical ventilation and any associated controls must be commissioned by testing and adjusted as necessary”. These Regulations cover the broad requirements for the systems, and are not designed to be comprehensive. For this there is a separate Domestic Compliance Ventilation Guide which gives users more details and assistance on how to comply with the Regulations

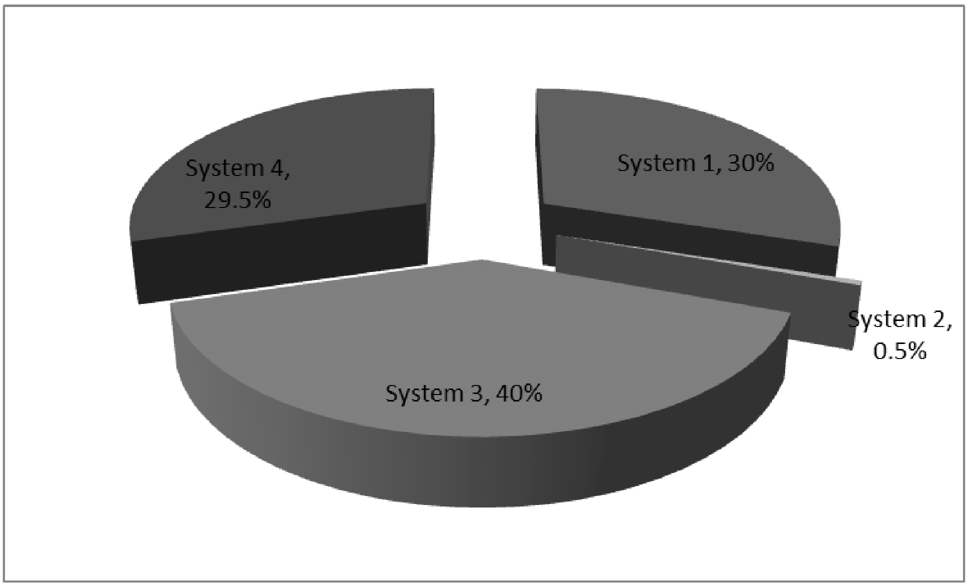

Figure 1: Percentage mix of new build ventilation system types in 2011

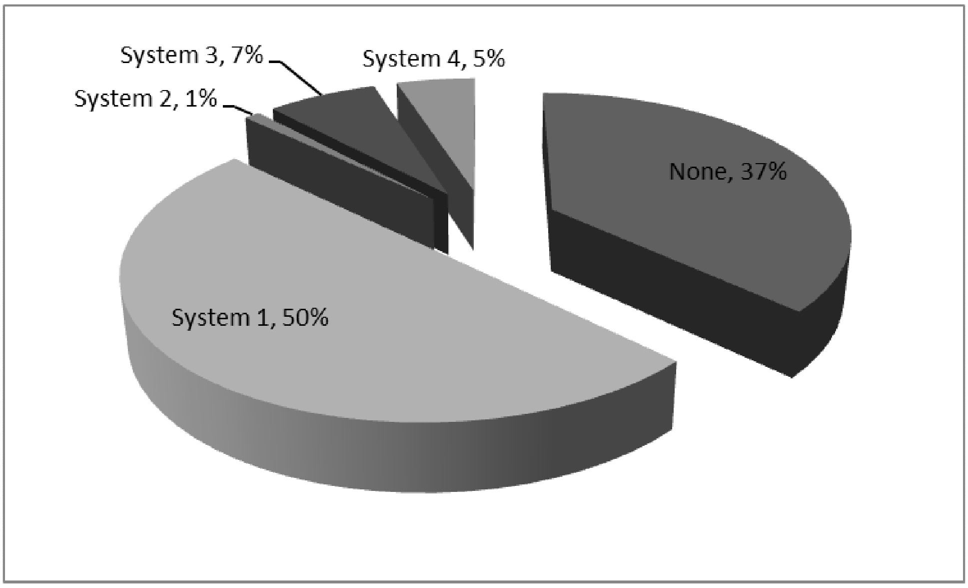

Figure 2: Percentage mix of ventilation system types in total UK housing stock in 2011

PRODUCTS

Background ventilators and intermittent extract fans, have no certification schemes in-place to uniformly define the product characteristics. Responsible manufacturers do however understand the role they can play in the quality of the installation, and provide system designers, installers and commissioners with a plethora of information in regard to how the products perform, along with how they should be used and installed. This often includes within their product manuals a replication of the details contained in the Building Regulations Ventilation Compliance Guide regarding installation, inspection and commissioning requirements.

For Mechanical Ventilation with Heat Recovery (MVHR) and Mechanical Extract Ventilation (MEV) systems uniform product characteristics are available via the Standard Assessment Procedure (SAP) Appendix Q. This data is available via a searchable website of performance data for technologies as well as products. The website also includes test and calculation methodologies that can be used to measure product performance

SAP is the methodology used by the Department of Energy & Climate Change (DECC) to assess and compare the energy and environmental performance of new dwellings. Its purpose is to provide accurate and reliable assessments of dwelling energy performances that are needed to underpin energy and environmental policy initiatives. SAP quantifies a dwelling's performance in terms of; energy use per unit floor area, a fuel-cost based energy efficiency rating (the SAP rating) and emissions of CO_2. With the exception of product that are listed in SAP Appendix Q there are no product labelling schemes defining product characteristics such as energy efficiency or fan performance in place within the UK. SAP Appendix Q requires products to display, the unique SAP identifier, the technology category, the brand name and model.

DESIGN

Whilst the design of ventilation systems is critical in obtaining correct operation, there are no national dedicated training schemes operated within the UK for designers. Many manufacturers do nevertheless offer a design service for their own systems based on meeting the requirements contained within the Building Regulations, and there are free practical guidance documents issued by organisations such as the NHBC Foundation (National House-Building Council) to help the industry meet the considerable design challenges [2][3]. Further guidance is due to be published mid 2013 from NHBC Standards which will detail a number of requirements in relation to the design of MVHR systems. These requirements are likely to include:

- MVHR location
- Guidance on the use of flexible ducting
- Positioning of air-valves
- Position of terminals (minimum distance between inlet and outlet)
- Maximum noise levels
- Definitions for summer bypass mode

NHBC is a warranty and insurance provider that provided standards for UK house-building for new and newly converted homes.

INSTALLATION AND COMMISSIONING

The UK Building Regulations state that ventilation systems should be "commissioned by testing" and the associated Compliance Guide details what this entails. It also states that a copy of all the completed documentation should form part of the systems Operation and Maintenance manual which should be left in the dwelling.

Both installation and commissioning are undertaken by the completion of a series of questions on a form which are broken down in to three main sections:
Part 1 – System details and declarations (manufacturer, make model serial numbers)
Part 2a – Installation details (type of ductwork, description of controls i.e. central, PIR etc., installation engineer's details)
Part 2b – Inspection of installation (general overview of system and visual of specifics such as condensate connections, duct insulation, inspector details)
Part 3 – Air flow measurement test and commissioning details (detailed breakdown of the design air flow rates and the measured air flow rates in each room at both low and high fan speeds where applicable, the test instrument used, date of last UKAS (ISO 17025) calibration, test engineers details).

For each installation all the parts of the forms need to be completed, and as a minimum Part 3 should be submitted to the Building Control Body (BCB) as evidence that the installation has been correctly tested and commissioned

It should be noted that commissioning does not normally include any fan power measurements, even though there is guidance on the maximum allowable figures for fans contained within the 2010 edition of the Domestic Building Services Compliance Guide. This document is similar to the Domestic Ventilation Compliance Guide, and is specifically designed to assist persons installing fixed building services in comply with the Building Regulations.

Value	Description
0.5 W/(l/s)	Intermittent extract systems
0.7 W/(l/s)	Continuous extract systems
0.5 W/(l/s)	Continuous supply systems
1.5 W/(l/s)	Continuous supply and extract with heat recovery systems

Table 2: Domestic Building Services Compliance Guide maximum specific fan power values for new and replacement systems

There are no current requirements contained in the Building Regulations for the assessment of noise levels from ventilation systems.

A single training course designed to meet the requirements of the manufacturers for the installation, inspection, testing, commissioning and provision of information for fixed domestic ventilation systems exists in the UK. This is organised by BPEC Services Ltd, and it is run by the majority of the UK ventilation system suppliers. The 2 day course includes a short examination, and if the candidate is successful they can register with a number of different bodies to become a Competent Person. Competent Persons are able to record their registration number / details on the forms that are submitted to the Building Control Bodies, and in doing this it allows the in-use figures in SAP Appendix Q to be used. If the person undertaking the test is not registered then a penalty is applied within the SAP calculation giving a different less favourable energy rating for the dwelling.

MAINTENANCE

Despite incorrectly installed ventilation systems having the capability of affecting the health of the occupants, and poor installations having a direct adverse impact on the cost of running the system, there are no large scale maintenance schemes operated within the UK for residential ventilation systems. Many would consider that this is as a result of very little information made available to the residents when they take occupancy of their home, but with the majority of the UK housing stock privately owned getting the message out to a wide audience of the importance of maintenance could be considered as an extremely difficult task. Individuals who have installed retrofit MVHR systems could be considered as being more aware of the need for maintenance, but there is growing evidence from manufacturers of systems that this is not being applied as the reported sales of replacement filters is low compared to systems in the market.

The only exception to this trend is that some local housing authorities are now playing a more active role in maintenance with systems in place that automatically link the replacement of filters in MVHR systems to their yearly inspections of the dwellings they rent. But, these schemes can be considered to be in the minority especially when considering the number of systems installed.

INSPECTIONS

Similar to the maintenance of systems, there are no dedicated schemes in-place within the UK for the regular inspection of residential ventilation systems, and there are no standards for training, labelling or certification schemes for any inspectors. There is an inspection process as part of the initial installation process and details are recorded on the installation and inspection sheet provided within the Domestic Ventilation Compliance Guide.

THE QUALITY OF INSTALLED VENTILATION SYSTEMS

In late 2011 BSRIA undertook a small independent study on 40 random properties constructed by different builders, with various ventilation systems employed to the requirements contained in 2010 version of Building Regulations to assess their performance characteristics. Where, an example testing can be seen in Figure 3. It found that that 95% of everything initially evaluated failed to meet the requirements of the Building Regulations with some installations having a number of failure modes. In undertaking this work it became evident that the test instrumentation used in commissioning out in the field was not meeting the requirements contained in the Compliance Guide.

Value	Description
33 (82.5%)	Ductwork incorrectly fitted (kinked / bent / poor joints / excessive length)
10 (25%)	Undersized fans to meet the minimum ventilation requirement
6 (15%)	Insufficient fans or terminal outlets for dwelling type
3	No boost function
3	Incorrect installation data
2	Missing ductwork
1	Blocked ductwork

Table 3: Ventilation system failure modes in a study of 40 dwellings

More specifically they were not UKAS (ISO 17025) calibrated for air volume. Some were calibrated for air velocity, not volume, but most equipment had no calibrations at all. The measurement instruments often failed to meet the 5% accuracy requirement, with some having a 1 l/s scale resolution that equated to a best measurement capability of 16.6% at 6.0l/s, the minimum rate specified for sanitary accommodation (WC cloakrooms etc.). Furthermore it became apparent that the influence of the measuring system employed could significantly affect the performance of the fan system itself, which is a finding similar to other studies conducted [4] [5]. Further testing within the BSRIA laboratories on their UKAS (ISO 17025) accredited test facilities, see Figure 4, into the influence of the measuring system on the ventilation system, revealed that the use of the traditional 100mm vane anemometer and plastic hood assemblies produced significantly variable results [6]. An example of which can be found in Figure 5.

Figure 3: Assessment of ventilation system performance using a powered flow hood

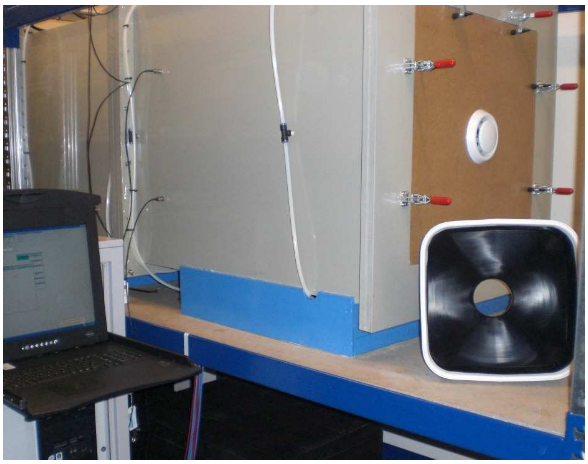

Figure 4: BSRIA UKAS (ISO 17025) accredited air volume test facility

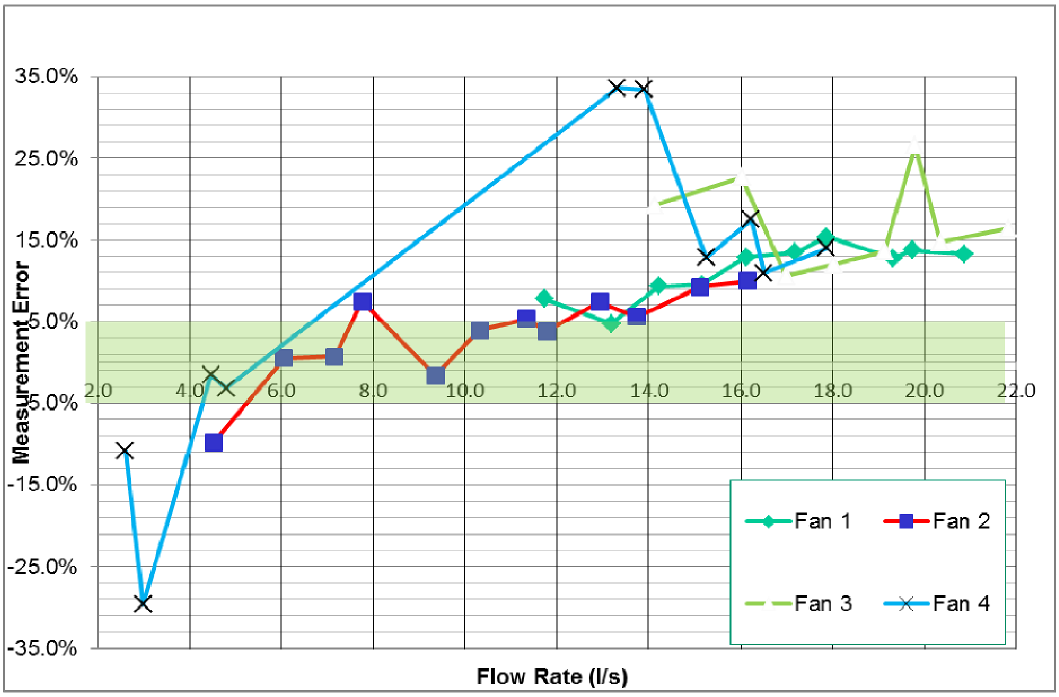

Figure 5: Typical measurement errors using a UKAS air volume calibrated vane anemometer with square hood on four different fan assemblies

Further investigation into this phenomena resulted in the publication of a BSRIA guide to measuring airflow rates in domestic ventilation systems [7], and this specifies that there are two methods that should be used for domestic installations – the unconditional method and the conditional method.

The unconditional method of airflow measurement uses a powered flow hood assembly, and is deemed as the preferred method in all installation scenarios because of its accuracy and simplicity. As the name suggests, it is a method that is free from site specific conditions such as fan type, model, airflow direction and instrumentation characteristics.

Whilst the unconditional method of airflow measurement is the preferred method for all type of domestic system, the conditional method employing systems such as a vane anemometer + hood can still be employed for some types of installation. However, as its name implies there is need to take into account specific site conditions such as the fan performance characteristics, the resistance to airflow created by the measurement device and assorted correction and conversion factors depending on the type of measuring equipment used. These correction factors are currently not available as every system is different, and only where a house builder is able to standardise on a dwelling type and a specific ventilation system type, will correction factors become available.

CONCLUSIONS

Based on the sample tested it is probable that within the UK a large number of installed ventilation systems do not comply with the requirements contained in the Building Regulations. Design was regularly compromised with inadequate installation, inspection and commissioning, along with the instrumentation used providing data that was wholly incorrect. Clearly this situation needs to change if the construction industry is to build better homes, and to meet the carbon reduction challenges ahead especially in regards to energy efficiency. Positive steps in this direction are currently being made, with for example the production of a freely available flow measurement guide, but only the firm implementation of the existing Regulations by the Building Control officers are likely to have any significant change on the overall quality of the build.

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QUALITY OF VENTILATION SYSTEMS IN RESIDENTIAL BUILDINGS: THE U.S. SITUATION

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Abstract

The United States does not have the tradition of residential ventilation systems that much of Europe enjoys and the situation in determining the quality of those systems is not well developed. California, the most advanced jurisdiction does have some requirements. Limited data suggest that whole-house ventilation systems in California don't always perform as code and forecasts predict. Deficiencies occur because systems are usually field assembled without design specifications, and there is no consistent process to identify and correct problems. The value of such activities in terms of reducing energy use and improving indoor air quality (IAQ) is poorly understood. Commissioning such systems, either when they are installed or during subsequent building retrofits, is a step towards eliminating deficiencies and optimizing the trade-off between energy use and IAQ.

The Lawrence Berkeley Laboratory completed a study for California to estimate the relative value that the quantity and quality of ventilation would have. The goal of this study was to determine the potential value of commissioning residential whole-house ventilation systems that are intended to comply with California's (Title 24) residential ventilation requirements. A physics-based modeling approach was used to assess the impact on occupant health and building energy use of malfunctioning whole-house ventilation systems. Energy and IAQ impacts were quantified and then compared by using the Time Dependent Valuation (TDV) approach for energy and a Disability Adjusted Life Year (DALY) approach for IAQ. Health benefits are predicted to dominate energy benefits independent of house size and climate. The metric for commissioning whole-house ventilation systems should be net present value of the combined energy and IAQ benefits to the consumer. Commissioning cost decisions should be made relative to that value even if that means ventilating to exceed the ASHRAE 62.2 minimum.

As a consequence of combining IAQ and energy costs, the beginnings of an approach to optimize the ventilation rates of homes was established.

KEYWORDS

Residential, Commissioning, Ventilation, Energy, Health, Indoor Air Quality

1. INTRODUCTION[1]

Until recently, whole-house mechanical ventilation systems were seldom installed in California houses. In 2008 to address potential concerns about diminished indoor air quality (IAQ), the state's Title 24 Energy Code [1] mandated that new homes comply with ASHRAE Standard 62.2 [2] that provides requirements for residential ventilation. These include minimum airflows for whole-house mechanical ventilation, local exhausts, and maximum net exhaust airflows for combustion safety. Standard 62.2 also states that delivered mechanical ventilation airflows must be measured, except for local exhaust systems with ducts that meet prescriptive sizing requirements or manufacturer's design criteria.

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[1] This article is adapted for the AIVC *Quality of Ventilations Systems* workshop March 2013 from:

Turner WJN, Logue JM, Wray CP. A combined energy and IAQ assessment of the potential value of commissioning residential mechanical ventilation systems. Building & Environment. 2013;60:194-201 [http://dx.doi.org/10.1016/j.buildenv.2012.10.016] (LBNL- 5969E)

Few measurements are available, but the limited data indicate that, where installed, these systems do not always perform as expected. For example, Stratton el al. [3] analyzed the flow rates of whole-house and local exhaust systems in 15 California homes. They found that only two of the tested homes met all ASHRAE 62.2 requirements. Offermann [4] found that, of the few ducted outdoor air systems in use in new California homes, many do not run often enough with sufficient flow to provide adequate ventilation. Such deficiencies occur because systems are field assembled (usually without design specifications), there is no consistent process to identify and correct problems, and the value of such activities in terms of reducing energy use and improving IAQ is unknown. Commissioning such systems when they are installed or during subsequent building retrofits is a step towards eliminating deficiencies and optimizing the trade-off between energy use and IAQ.

According to ASHRAE, the building commissioning process is defined as "a quality-oriented process for achieving, verifying, and documenting that the performance of facilities, systems, and assemblies meets defined objectives and criteria" [5]. The results of the commissioning process are used to determine whether changes to the building system are warranted. Every commissioning process includes three principal elements: metrics, diagnostics, and norms [6-8]. For whole buildings, there are two broad performance metrics of interest: energy use and IAQ. To assure whole-building performance, it is also necessary to consider the relationships between metrics for interacting components and systems [9]. For example, house size and airtightness, mechanical ventilation airflows, and pollutant emission rates must be quantified to understand the impact of ventilation on energy use and IAQ. Under the assumption that the quality of outdoor air is better than indoor air, increasing ventilation airflows will improve IAQ, but will also increase energy use. Diagnostics in the form of relatively quick short-term measurements can be used to evaluate such metrics. The norms will refer to the expected level of performance delivered by a system or piece of equipment. In the case of residential ventilation for new houses, Title 24 uses ASHRAE 62.2 to provide norms for comparison, in the form of minimum ventilation rates. Quantifying energy and IAQ performance is only the first step in a commissioning process. The potential *value* that commissioning provides by improving performance also needs to be evaluated. Decisions can then be made about whether or not it is cost effective to alter performance.

How commissioning is performed is usually dependent on who is conducting the commissioning and for what purpose. For builders complying with ASHRAE 62.2, most use a prescriptive approach. The metric in this case is code compliance. The norm is to use the prescribed fan size and ducts. The diagnostics are to confirm that the duct systems meet the prescribed requirements. Tuning only occurs if the duct and fan system are obviously not meeting the prescribed standards. Those commissioning to meet the intent of ASHRAE 62.2 tend to use a different approach. In this case, the metric is airflow rate, which is measured using flow measurement devices. The norm is meeting the ASHRAE 62.2 minimum airflow rate. Tuning would be to adjust over or under performing systems to the norm.

Literature about commissioning installed ASHRAE 62.2 systems is limited. However, the small number of studies generally focus on the metric of airflow rate and evaluate whether ventilation systems comply with ASHRAE 62.2 [10]. The underlying assumption is that ASHRAE 62.2 provides the correct amount of ventilation to provide good IAQ, and that the optimal goal is to meet that requirement with as little energy as possible. The decision to adjust the system would be evaluated based on meeting ASHRAE 62.2 in the most cost effective manner. Independent studies have shown that even when ASHRAE 62.2 is met in new California homes, existing health-based pollutant concentration standards may not be met [10].

The goal of this work was to explore the potential of using comprehensive health and energy benefits of a ventilation system to assess whether the system should be tuned. The idea being that the cost of tuning the system should be less than the potential benefits of the change. In this context, the metric would be the combined health and energy benefit due to whole-house mechanical ventilation, the diagnostics would be airflow measurements and pollutant emission rates, and the norm would be the maximum benefit for a given home. The advantage of this approach is that we will be commissioning to maximum benefit for the occupants, and not to comply with a standard alone - as this may result in a net cost to the occupants.

In this study, we used computer simulations to compare and combine energy and IAQ benefits/costs of whole-house ventilation systems for a set of modeled houses representative of new California homes. We compared homes that met the norm of ASHRAE 62.2 to those that under- and over-ventilated in comparison to the standard. The results were used to assess the potential benefits of commissioning, and to suggest diagnostics.

2. BACKGROUND

The U.S. does not have a tradition of designed ventilation systems in dwellings. Requirements for mechanical systems are not yet widespread, but with the existance of ASHRAE Standard 62.2 and regulation required in at least some jurisdictions, it is clear that quality of ventilation systems will eventually be an important factor.

As backround, we present some of the current situation below, but is important to remember that the industry for both new and exisiting homes is just learning about residential ventilation. Before a philosophy of quality can be promulgated, the industry needs to become familiar with the technologies and the issues of implementing it.

2.1. Market

Very little (probably less than 5%) of the US stock has whole-house mechanical ventilation systems. Some (but likely less than 20% of) new homes have it. Simple, continous exhaust is the most common compliance method, with HRV/ERV being more common in high-end, high-performance homes.

The largest jurisdictions requiring mechanical ventilation is the state of California, which requires the use of ASHRAE Standard 62.2. The bulk of this paper focusses on the California program and the value that residential ventilation has. Other jurisdictions and many voluntary programs also require the use of ASHRAE 62.2 and that number will continue to grow.

While ASHRAE standards are not norms, they serve as the basis for which norms can be mandated. ASHRAE is the only body authorized to write American National Standards for residential ventilation.

2.2. Products

Home ventilating products can be rated by the Home Ventilating Institute (HVI: http://www.hvi.org), which is an industry group which lists products and offers 3rd party certification to specific standards. Some programs and ASHRAE Standard 62.2 require products comply with some of those standards, including requirements that as-installed flows be measured in some cases. Some organizations such as the Building Performance Institute (BPI: http://www.bpi.org) has guidelines to add in the installation of ventilation systems and offers its own certifications for practitioners.

2.3. Designs

Codes, standards and guidelines for residential ventilation focus on the design of mechanical ventilation systems (i.e. ASHRAE Standard 62.2 is a design standard). There is no overall certification scheme for the designers, although some programs may require that the person doing it have some relevant registration which covers more than just the ventilation area. Various educations entities offer training in meeting specific standards or programs. Only mechanical designs are accepted. While an allowance for air leakage may be included, natural ventilation and hybrid ventilation systems are not acceptable.

2.4. Installation, Commissioning, Inspections and Maintenance

The training for installation is usually combined with the training for design, especially in programs for existing buildings. There are no labelling schemes and there is no feedback. Commissioning is not done in the broad sense. Standard 62.2 requires that certain flows be field verified.

Simlarly inspections are not generally done. While in principle formal inspections could be done, it is exceedingly rare in practice. As in many kinds of design approaches formal quality assurance uses 3rd party declarations, which may or may not have actual inspections. Similarly maintenance is not a formal process. Occupants are expected to do the maintenance and are presumed to know how to do operations and maintenance from the instructions provided.

2.5. Potential impact on energy performance calculations

It is well understood that the lack of quality control of design, installation, commissioning and maintenance will result in less than optimal performance, but residential ventilation is not the only area in which this situation occurs. There are broad interests hoping to improve the performance of buildings and building regulations by requiring improved proceses. Because ventilation-related systems impact health and safety, it may happen earlier in this area than for those areas that only impact energy.

Currently energy performance calculations do not take quality of residential ventilation systems into account—neither do the IAQ performance calculations. Using the DALY approach the latter can be achieved and incorportate ventilation rates. The 2013 version of Standard 62.2, however, does allow the air leakage performance of the envelope to be included in botht the energy and IAQ sides of the equation.

3. COMMISSIONING ESTIMATION METHOD

To demonstrate the potential value of commissioning residential ventilation systems, we focused on faults that might occur in a whole-house mechanical exhaust system. The system faults caused either under-ventilation and reduced IAQ, or over-ventilation and increased energy use. The energy and IAQ impacts were converted to a monetary value using a Time Dependent Valuation (TDV) approach for energy and a Disability Adjusted Life Year (DALY) impact assessment approach for IAQ. We combined the monetary impacts over a 30-year period to represent the net present value (NPV) of the fiscal cost/benefit to the endpoint user (not including the actual cost of commissioning, as this was beyond the scope of this work).

3.1. Residential Energy and Airflow Modeling

To perform the simulations, we used REGCAP – a residential building energy and ventilation simulation tool with mass, heat, and moisture transport models [11]. REGCAP was used to determine the HVAC system energy use and air exchange rates of a set of representative homes on a minute-by-minute basis for a calendar year.

We simulated three houses typical to California with various ventilation system malfunctions that could be identified and rectified by commissioning. The three houses had occupied floor areas of 111 m^2, 195 m^2 and 250 m^2 (1,200 ft^2, 2,100 ft^2 and 2,700 ft^2 respectively) and were based on CEC Title 24 housing prototypes [12, 13]. Each house was modeled in three California climate zones: Oakland (CZ3, coastal), Sacramento (CZ12, hot) and Mount Shasta (CZ16, cold) as defined by the CEC [1]. Weather data files used were the Title 24 compliant TMY3 hourly weather data files [14] published by NREL.

3.1.1. Whole-House Ventilation Systems

For ASHRAE Standard 62.2, whole-house mechanical ventilation is sized as follows:

$$Q(L/s) = 0.05A_{floor}(m^2) + 3.5(N+1)$$
$$Q(cfm) = 0.01A_{floor}(ft^2) + 7.5(N+1) \quad (1)$$

Where, Q = the minimum required whole-house airflow rate [L/s and cfm], and N = the number of bedrooms in the house.

The ASHRAE 62.2 minimum airflow rate was used as a baseline for normal operation of the mechanical whole-house exhaust. The airflow rate was then simulated at 25%, 50%, and 75% of the 62.2 airflow rate to model underperforming ventilation strategies with inadequate airflows. Airflow rates of 200% and 300% of the ASHRAE 62.2 rate were also simulated to model malfunctioning intermittent fans to determine if there were any advantages or disadvantages to over-ventilation compared to the 62.2 minimum. All whole-house fans operated continuously for 24 hours per day, 7 days per week.

3.2. Indoor Contaminant Concentrations and Occupant Exposures

Because this analysis is focused on commissioning the airflow rates of whole-house ventilation systems, we only considered the impact on controlling the continuously emitted pollutants of interest. Logue et al [15] determined that three pollutants are the dominant contributors to the chronic burden of indoor health: formaldehyde, acrolein, and $PM_{2.5}$. This work is focused on determining the cost effectiveness of commissioning the airflow rates of whole-house ventilation systems alone, so $PM_{2.5}$ was not considered as it is a filtration issue and not an airflow rate issue. For a full discussion on this assumption the reader is referred to the main article [16].

We calculated indoor concentrations over the course of a year as a function of building air change and pollutant emission rates using a simple time-step mass balance approach. For each of the three homes in each of the three climate zones, we simulated the indoor concentrations of formaldehyde and acrolein with three levels of pollutant loading (low, medium and high). Formaldehyde emission rates were derived from measurements taken by Offermann [4]. The acrolein emission rates were derived from the acrolein measurements by Seaman et al. [17]. The 5th, 50th, and 95th percentile emission rate values from each of the data sets were used as the low, medium, and high emission rates (see Table 1). The outdoor concentrations (also Table 1) were taken from the National Air Toxics Assessment (NATA) 2002 modeling results [18].

Table 1: Emission rates (ER) for formaldehyde and acrolein with outdoor concentrations [4, 17, 18]

Pollutant	Emission Rate, ER [*µg/(h m^2)*]			Outdoor Concentration [*µg/m^3*]		
	Low ER	Medium ER	High ER	CZ 3	CZ 12	CZ 16
Formaldehyde	9.7	30.3	88.2	2.9	2.9	3.0
Acrolein	1.3	1.9	6.1	0.08	0.08	0.07

3.3. Monetization of Energy and IAQ Benefits and Costs

3.3.1. Time Dependent Valuation (TDV) of Residential Energy Use

TDV is an attempt by the CEC to weight California energy saved during peak demand periods more preferentially, while the distribution grid is operating at or close to capacity [19]. TDV factors are given in units of energy (kBtu/kWh) and can be converted to NPV in 2011 US dollars based on 30 years of operation using a conversion factor of 0.1732 (with units of $/TDV kBtu) for low-rise residential buildings. A 3% real, inflation-adjusted discount rate was used to forecast the gas and electricity rates over the 30 years. For the purposes of this work, the electricity and gas TDV factors for California climate zones 3 (Oakland), 12 (Sacramento), and 16 (Mount Shasta) were applied to the simulated hourly energy use of the HVAC equipment. This gave us the monetary cost or gain over a 30-year period for the different ventilation scenarios.

3.3.2. Disability Adjusted Life Year (DALY)

DALYs are a measure of overall disease burden and incorporate both disease likelihood and severity [20, 21]. DALYs are reported as the equivalent number of years lost from premature death and disability. They offer a way to compare mortality and morbidity. To determine the total number of DALYs lost due to changes in exposure per year, we used the impact assessment methodology developed by Huijbregts et al. [22]. To determine the NPV of changes in exposure for each simulation for 30 years (to allow comparison with the 30-year TDV energy NPV), we determined the annual cost of DALYs lost or gained relative to a system that was operating at the level specified by ASHRAE 62.2. The projected value for each DALY is of the order of US $50,000 to $160,000 [23, 24]. For this project, we assumed a central cost of $100,000 per DALY lost in 2011 US dollars per household occupant. We applied a discount rate of 3%, the same discount rate applied to the energy analysis.

4. RESULTS AND DISCUSSION

3.1 Commissioning Whole-House Ventilation Rates

The energy components are dominated by the space-conditioning load and so are dependent on climate and house size. The health components are dependent on the ventilation rate, which scales with house size and number of occupants, and is independent of climate. However, the health components dominate the energy components. As a consequence, the results may be applied to other regions and countries, not just California. The discussion presents results only for the medium sized house (195 m^2) in Sacramento (Climate Zone 12).

Combining the DALY dollar cost associated with IAQ, with the TDV dollar cost associated with energy use, allowed us to show the dollar cost or benefit over 30 years from commissioning to fix a malfunctioning whole-house ventilation system so that it complies with ASHRAE 62.2. All of the monetary results presented here are for the NPV of the 30-year health benefits and energy costs for a single model home in 2011 US dollars. The NPV values are the difference between the malfunctioning systems and the norm i.e., a system operating as specified by ASHRAE 62.2.

The ASHRAE 62.2 whole-house minimum mechanical ventilation airflow rate (from equation (1)) is 24 L/s [51cfm] for the prototype, C house. Figure 1 shows the breakdown between the energy and the IAQ components for 0%, 25%, 50%, 75%, 100%, 200% and 300% of the ASHRAE 62.2 ventilation rates. Figure 2 demonstrates the combined energy and IAQ benefit. A positive dollar value represents money saved while a negative dollar value represents money lost.

The 100% ASHRAE 62.2 ventilation rate was taken as the norm to which the other ventilation rates were compared. Under-ventilation represents an energy benefit from reduced mechanical ventilation energy and reduced heating and air conditioning loads, and an IAQ cost from higher contaminant levels. Conversely, over-ventilation represents an energy cost from higher fan energy use and increased space conditioning loads, and an IAQ benefit from reduced contaminant levels.

As an example, consider the 50% ASHRAE 62.2 ventilation rate case (this is a whole-house exhaust fan underperforming and so delivering only half the 62.2 ventilation rate) from Figure 1. The TDV energy financial benefit is $576 over 30 years. This represents money saved on energy bills due to the decreased ventilation rate. For the medium contaminant emission house with the same 50% airflow rate, the IAQ financial benefit is negative $1,639 over 30 years. This represents money lost (or cost) due to reduced air quality from exposure to indoor contaminants. When the energy and IAQ costs are combined in Figure 2, the net benefit is negative $1,063 which represents an overall loss (the financial value of the energy saved is less than the financial value of life lost due to higher contaminant levels).

The worst case is a non-functioning (0% of the 62.2 airflow rate) whole-house exhaust system in the high emission house. This will cost the occupants approximately $8,700 net over 30 years. Over ventilating the same high emission house with an airflow rate of 300% the 62.2 minimum will gain the occupant approximately $7,100 net (a $15,800 difference). In the latter case, fixing the system to meet ASHRAE 62.2 would actually be detrimental to the occupants as the value of the energy saved from reducing the system airflow rate is vastly outweighed by the benefit from improved IAQ.

Results for the whole-house exhaust fan are highly dependent on the continuous contaminant emission rates. In medium and high emission homes, commissioning could play a vital role in improving IAQ where whole-house ventilation systems are not providing adequate airflow rates. Over 30 years, the health benefit in 2011 US dollars from ventilating properly vastly outweighs the energy benefit from under-ventilating. However, when the malfunction provides over-ventilation in medium and high emission homes, an airflow-only based commissioning process could actually be detrimental to the occupants because fixing the malfunction would reduce the mechanical ventilation airflow rate and increase the health cost. This suggests that commissioning processes for whole-house ventilation systems should include both energy use and IAQ as metrics. The results also suggest that controlling and limiting the levels of continuous contaminant emissions may be an important tuning tool for residential ventilation systems. Labeling schemes now exist for products that meet low emission standards, such as California Section 01350 [25]. The commissioning process could involve the practitioner looking for labeled products in the house to help quantity the levels of continuous emissions.

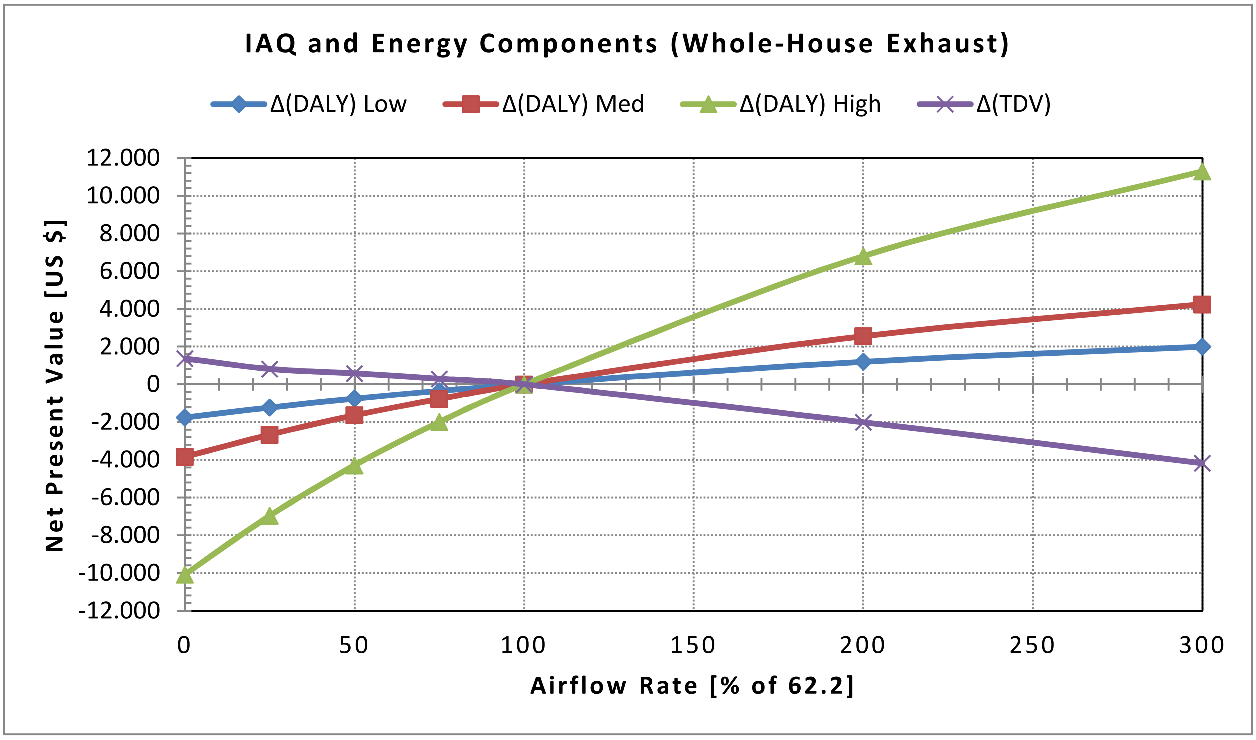

Figure 1: IAQ and energy components, relative to 100% of the ASHRAE 62.2 airflow rate, for the NPV of commissioning a malfunctioning 62.2 whole-house exhaust for three contaminant emission rates (low, med and high). 100% is equal to 24 L/s [51 cfm]. Results are for the 195m^2 house in Sacramento

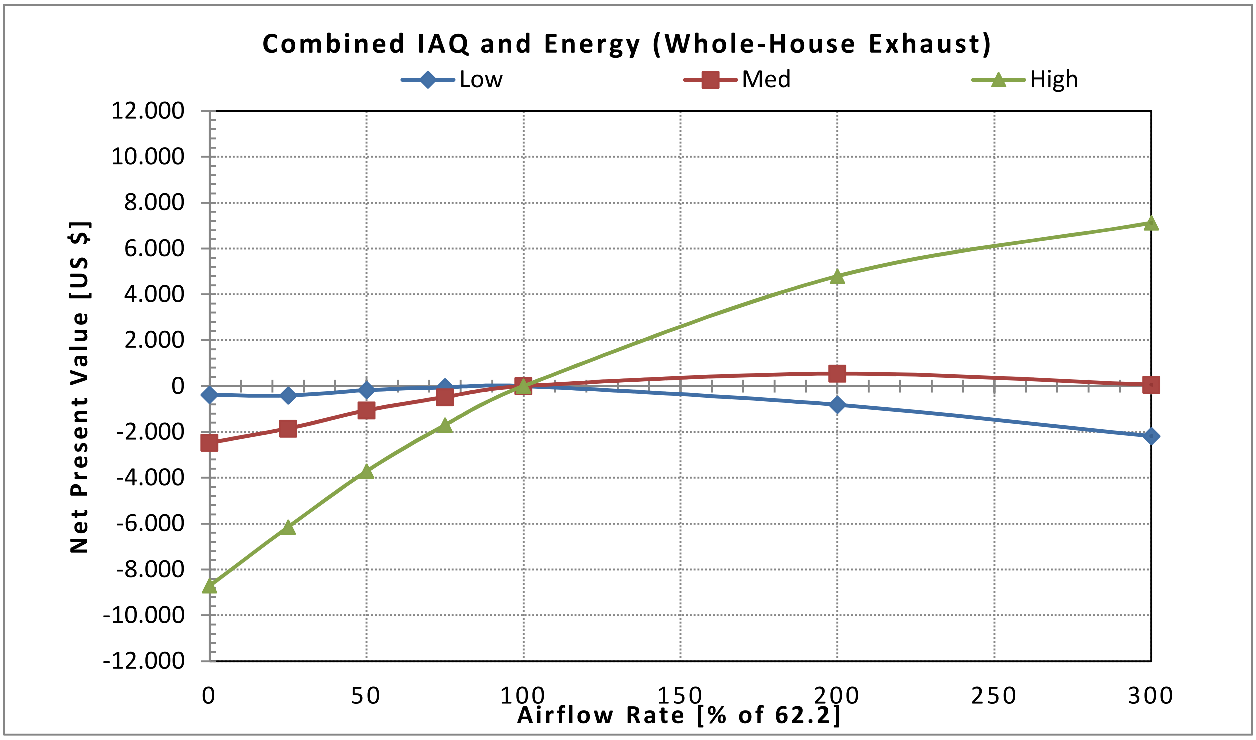

Figure 2: Combined IAQ and energy Net Present Value from commissioning a malfunctioning 62.2 whole-house exhaust for three contaminant emission rates (low, med and high). Results are for the 195m^2 house in Sacramento

3.2 Ventilation Rate Optimization

As a result of combining IAQ and energy costs, it is also possible to attempt to optimize the ventilation rate to find the most cost-effective level of IAQ. Figure 3 shows the 30-year absolute NPV in US dollars once the IAQ and energy values have been combined.

Assuming a binomial relationship, the curves in Figure 3 have been extrapolated past the 300% ASHRAE 62.2 airflow rate that was modeled. The optimum ventilation rates are at the local minima, or where the differentials of the curves are equal to zero. For the high emission house the optimum airflow rate was approximately 310% of the 62.2 minimum. For the medium emission house it was around 200%. For the low emission house the optimum ventilation rate was approximately 85% of the 62.2 minimum. This approach is highly dependent on emission rates, but the high and low emission rates used in this study should act as boundary conditions. Further work will be needed to apply this method to ventilation standards, but the results suggest that ventilation rates prescribed by ASHRAE 62.2 could be too low for dwellings other than low-emission houses.

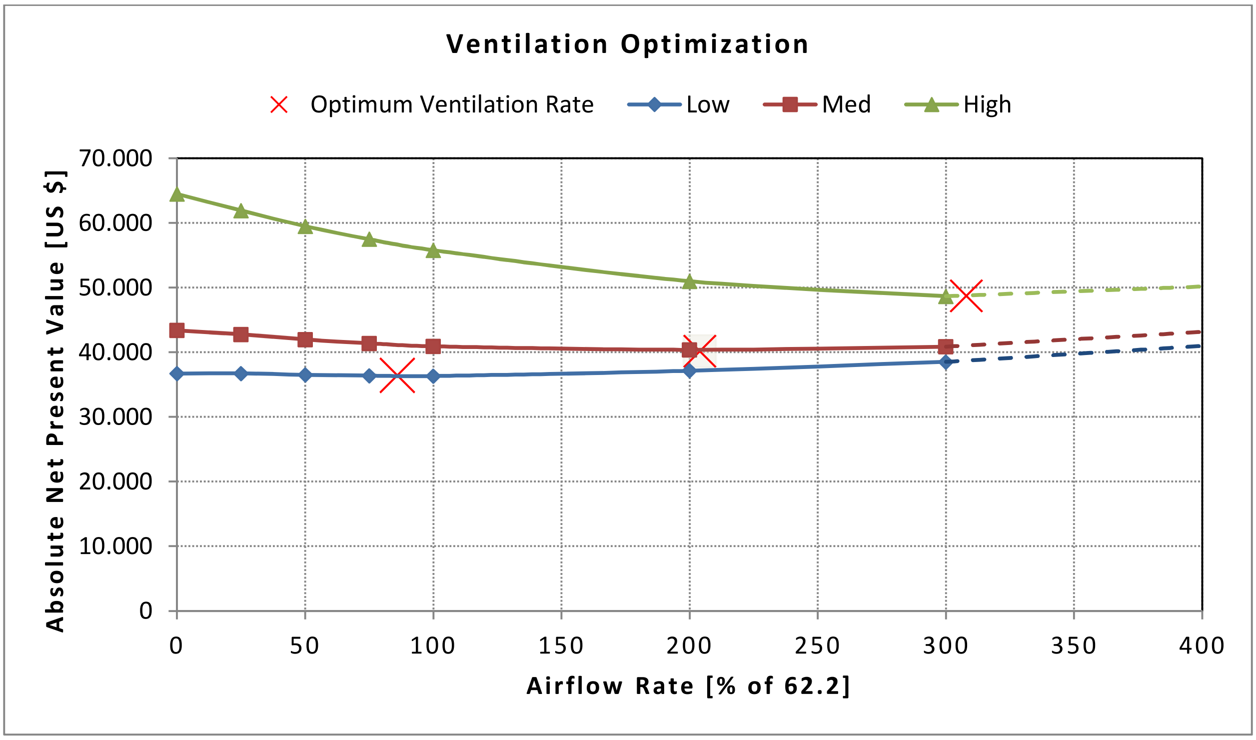

Figure 3: Optimization curves for IAQ and energy. The local minima are the points representing the minimum cost to the occupants

5. CONCLUSIONS AND RECOMMENDATIONS

Our results show that health benefits dominate over energy benefits when converted to US dollars using DALY and TDV approaches. This was independent of house size and climate. The potential health impacts were large when ventilation rates were insufficient to dilute the emitted indoor contaminants. Providing minimum airflow rates to comply with ASHRAE Standard 62.2 alone is not a sufficient metric for commissioning whole-house ventilation systems and ideally, decisions about tuning should be made with knowledge on indoor pollutant emission rates, ventilation airflow rates, and outdoor air quality. The metric should be NPV of the combined energy and IAQ benefits to the consumer and commissioning cost decisions should be made relative to that value even if that means ventilating to exceed the ASHRAE 62.2 minimum. Identifying that diagnostics are needed to quantify emission rates will hopefully spur industry to develop an appropriate tool for the commissioning community. Identification of low emission products contained within the home via labeling schemes could be part of the commissioning process. As a consequence of combining energy costs with monetized IAQ costs we now have the beginnings of an approach to optimize the ventilation rates of homes.

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