JOULE

Programme 1994-98

Towards improved performances of mechanical ventilation systems

TIP-Vent

FOREWORD

This document was written in the framework of the European *TIP-Vent* project (Non Nuclear Energy Programme JOULE IV). The acronym means : Towards Improved Performances of mechanical Ventilation systems.

The aim of the *TIP-Vent* project is to :

- have a better understanding of the impact of ventilation rates on energy consumption;
- have a better knowledge of the real performances of existing ventilation systems;
- make an overview of the European standards concerning ventilation and a study of their impact on performances;
- develop a performance oriented approach;
- develop smart components, controls and systems;
- develop guidelines for the application of the developed concept;
- transfer the outcomes of the research to professionals.

The research participants (also called the *TIP-Vent* Partners) are :

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  Division of Building Physics and Indoor Climate - Belgium
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More information on *TIP-Vent* partners

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- Swedish National Energy Administration
  Sweden
- Swedish Council for Building Research
  Sweden
- University of Porto - Portugal
- TNO Building and Construction Research
  Division of Systems and Buildings
  The Netherlands
- Ministry of Economic Affairs
  The Netherlands

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1 INTRODUCTION

The major aim of the *TIP-Vent* project was to give a substantial contribution to the creation of better boundary conditions for the application of mechanical ventilation systems with good performances.

Given the challenges (see chapter 2) of the *TIP-Vent* project, a consortium was set up which brought together a wide range of disciplines as well as expert knowledge in various ventilation related fields : performance assessment by computer simulation and monitoring in situ, standardisation activities, project consultancy, product and system development.

The practical actions have been organised through 7 tasks. This book aims to summarise the major outcomes of the EC JOULE *TIP-Vent* project.

In addition to this book, there are a range of reports which present in detail the findings of the various tasks (see chapter 10.1). Hyperlinks in this report allow to a direct link with these reports.

The project partners have decided to publish the book only on CD-ROM. This approach allows a cheap production and, therefore, a wide distribution. Moreover, all the related reports can also be included on the CD-ROM without extra cost.

During the duration of the project, a website was operational to give information on the status of the project.

2 THE TIP-VENT CHALLENGES

The *TIP-Vent* project had the following objectives:

1. Achieving a better understanding of the impact of air flow rate requirements found in standards on the energy demand of buildings (residential and non-residential sector) and the existing background for the specifications of ventilation requirements.
2. Evaluating for a selection of buildings (residential and non-residential) equipped with mechanical ventilation the level of agreement between:
   - required, design and real air flow rates;
   - required, design and real noise levels;
   - required, design and real draught performances;
   - the desirable and real fan consumption;
   - desirable and real air quality of the supply air.
3. Analysing in the participating member countries (south, central and north of Europe), as well as in some other countries with interesting approaches, the impact of existing and proposed standards and building regulations on the performances of ventilation systems.
4. Creating a pre-normative framework / platform (performance oriented approach and procedures for on site checking,…) that will stimulate the development and the market entry of smart mechanical ventilation designs, systems and strategies.
5. Applying/testing the developed concept on a representative range of systems.
6. Developing a number of new innovative ‘smart’ designs for improved performances with emphasis on active acoustical insulation, demand control ventilation, low pressure mechanical ventilation and intelligent fan control.

The *TIP-Vent* consortium of industrial companies and research teams has identified actions which can lead to improved performances of mechanical ventilation systems and the introduction and wider use of innovative ventilation designs. The development of performance oriented procedures for designing, commissioning and maintaining mechanical ventilation systems plays a central role in the structure of this project. The following chart shows the different tasks and their links.

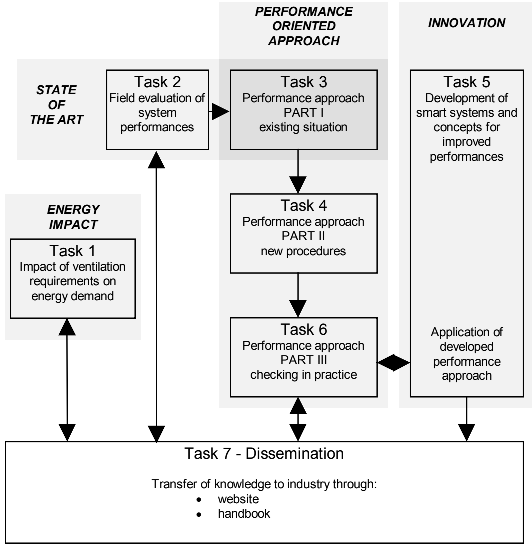


Figure 1 : Relation between the different tasks within the TIP-Vent project

Task 1 aim to achieve a good understanding of the exact <u>energy consequences</u> due to ventilation requirements for residential and non-residential buildings. The major findings are reported in chapter 5 ‘Energy use due to ventilation’ 🗎.

Tasks 2 and 3 had as objective to evaluate the <u>present situation</u> regarding the real performances of systems (in-situ evaluation) and regarding the impact of existing European standards and regulations on the performances of mechanical ventilation systems and on the market penetration of smart designs. The information in chapter 6.1 (‘Ventilation performances in daily practice : requirements of ventilation systems’ 🗎) is based on the work of task 3 whereas chapter 6.3 (‘Ventilation performances in daily practice : examples of system performances’🗎) reports information collected in task 2.

Task 4 was devoted to the development of <u>new procedures/approaches</u> that are <u>performance oriented</u> and which can form a framework/platform for future standardisation or regulations in Europe. Chapter 7 contains a summary of its conclusions 🗎.

Task 5 consisted of <u>developing new smart products</u> aimed at improving the performances of ventilation systems. The outcome of this work is reported in chapter 9 🗎.

Results of task 4 were checked in practice by developing guidelines for practitioners in task 6.

The guidelines cover the entire life cycle of a ventilation system and were tested on the systems developed in the framework of this project. The outcome of this work is reported in chapter 7.3 .

Task 7 was aimed at transferring the knowledge from this project to the industry by means of a website on the internet and this source book. This website was operational during the duration of the *TIP-Vent* project.

3 PERFORMANCES AND QUALITY OF VENTILATION SYSTEMS

All systems, including ventilation systems, can be characterised by a set of performances. In principle, one might expect that a system is of good quality. The issue of quality is a key area of concern for many industrial sectors. In the framework of the ISO standard 8402, quality is defined as *'Totally of characteristics of an entity that bear on its ability to satisfy stated and implied needs'', whereby 'stated' corresponds with 'expressed' and 'implied' with 'evident'. An 'entity' can be e.g. a ventilation component or a ventilation system.*

The suppliers are assumed to deliver entities which meet the requirements for quality (Figure 2, ❶). The customer is in a position to identify his needs (Figure 2, ❷) with respect to a certain entity. Besides the customer, society can also impose certain performances. These performances (also called the requirements of society) (Figure 2, ❸) can be specified in standard, regulations,… Ideally, the needs of the customer and the requirements of society should cover all the needs. However, certain needs may not be covered (Figure 2, ❹). Based on the requirements for quality, the supplier is assumed to deliver an entity. Quality assurance (Figure 2, ❺) is in most cases crucial to guarantee compliance with the requirements for quality. Such assurance procedures can be done by the customer and/or by society. Of course, if certain needs are not covered by the requirements for quality, it is not evident to carry out quality assurance on these aspects (Figure 2, ❻).

In many industrial sectors, it has become common practice to develop quality schemes in line with Figure 2. Often, the role of society in expressing the requirements is relatively limited. However, the role of society can be very important, e.g. in relation to environmental concerns,…

As far as the building sector is concerned, there are requirements for quality for a whole range of products and technologies. Examples are the requirements for concrete structure (strength, deformation, material composition,…), for thermal insulation materials,… For certain performance aspects, it is less crucial to have clearly stated requirements for quality since there is common sense (it expresses 'implied' needs) with respect to the quality expectation. Examples are water tightness of plumbing, lack of condensation in double glazing, lack of condensation and mould formation on indoor surfaces, etc.

For indoor climate aspects as well as for energy efficiency aspects, it seems less evident to count on implied needs. This is in particular the case for mechanical ventilation systems.

The reasons include:

- The needs are often not evident : what is the required ductwork airtightness, what level of energy efficiency is required, what are the required acoustical performances, what are allowed under- or overpressures in buildings,…
- The customer is often not able to (easily) identify non compliance. Therefore, precise requirement levels in combination with correctly stated procedures are crucial.

Practice shows that, unless such requirements and procedures are applied, one often finds performances which are (substantially) below reasonable performance levels. This is also shown in task 2 of the *TIP-Vent* project. (de Gids, 1999) [Ref 9]

The global quality of a mechanical ventilation system is not only the result of the component performances nor of the quality of the design. In practice, it is the combined result of the quality of the **design**, the **component** performances and the quality of **execution and maintenance**. (Figure 3). Therefore, the designers, the industry and the building contractors are all jointly concerned. In the case of mechanical ventilation systems, it appears that the quality of execution is often of extreme importance. Within the framework of the *TIP-Vent* project, those 3 aspects have received attention. Moreover, the interaction between those 3 aspects (e.g. how can optimisation of design and/or components influence the impact of the quality of execution) has been studied.

The *TIP-Vent* activities allow the conclusion to be drawn that in general, but particularly in the case of mechanical ventilation systems, it is not possible to make a judgement of quality and/or performance unless the requirements of quality (by the customer, by society) are well identified. Given the fact that many customers have no or very vague requirements and that often the requirements of society are weak, many ventilation systems are poor performing but still accepted by the customers and society.

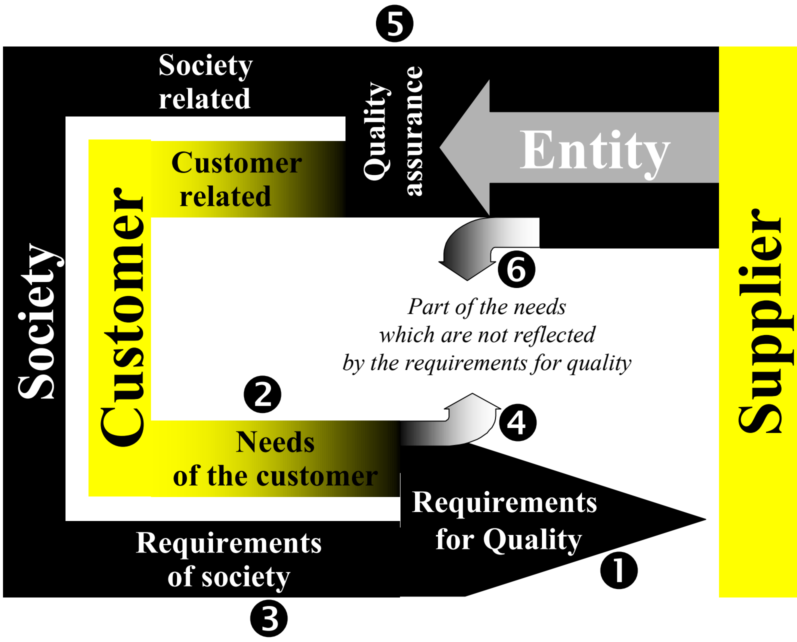


Figure 2 : Global context for determining quality and performances according to ISO 8402

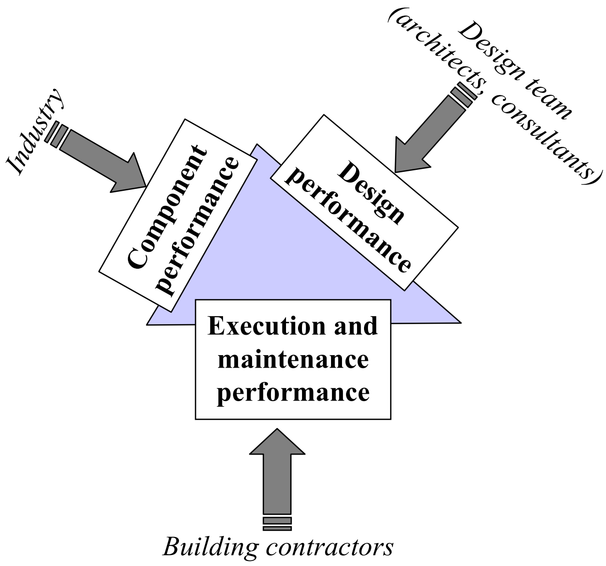


Figure 3 : Crucial aspects for achieving mechanical ventilation systems with good performances

4 VENTILATION REQUIREMENTS

4.1 VARIOUS TYPES OF STANDARDS

Ventilation in buildings is required to:

- deliver fresh (outside) air for people in rooms
- dilute and remove polluted air from the building
- reduce peoples exposure to microbiological hazards
- prevent moisture damage to the building construction.

The ventilation requirements in standards in most cases are descriptive. Descriptive means in this view that the requirements are specified more in terms of solutions. In the descriptive approach for indoor air quality control, one avoids to a large extent the need to specify the boundary conditions and the 'real objectives' to be achieved. By assuming certain default values, it is then often possible to come to requirements, which are less complex and easier to be understood, by most designers and installers.

For ventilation in most standards flow rates are specified. In some cases even how these flow rates may be provided for instance by mechanical or natural ventilation. In the case of natural ventilation, standards may specify openable areas, such as windows.
The opposite of descriptive is performance oriented specifications.
A performance oriented approach is focused on the real (or assumed) user needs whereas a descriptive approach is more focused on describing acceptable solutions (Wouters, 2000) [Ref 41]. The differences between the performance and the descriptive approach can be illustrated by the example of specifications in relation to indoor air quality. In a ***performance oriented standard*** for indoor air quality control, one will express the required 'real objectives'. This can be achieved by defining for a series of pollutants (eg CO, TVOC, CO_2, NO_X, dust). the maximum concentrations, the acceptable dose and the boundary conditions for which the requirements must be met.

In order to guarantee such specifications, one needs in most cases a ventilation system. It is clear that it is not possible to guarantee for all possible situations of outdoor climate and internal pollution sources that the requirements will be met. Therefore, a performance oriented standard must specify the boundary conditions, e.g. what are the maximum outdoor pollution levels.
The performance oriented approach assumes that it is possible to explicitly define the requirements to be realised as well as the boundary conditions. In order to prove that the requirements are met, this may require the use of rather complex calculation or testing procedures.
In theory, a fully performance oriented approach is preferable.

The real performance objective for ventilation is to minimise the exposure of people to hazardous compounds in buildings such as emissions from building materials and furniture and bio-effluents produced by people themselves. It is quite difficult to define what the exposure of people may be.
Since ventilation is the exchange of air between inside and outside energy is required to heat the air to the required indoor temperature level during the heating season. In some countries nowadays the consequence of ventilation in terms of energy is included in energy performance standards.
Ventilation also causes air movement in rooms; therefore it has an effect on comfort in rooms. In most cases a certain maximum air velocity in a room is specified in relation to the room temperature.
The movement of air as a result of ventilation systems is a source of noise. In most standards there are requirements for maximum sound power levels due to systems.

4.2 LITTLE KNOWLEDGE CONCERNING THE REAL NEEDS

Although the air flow rates are sometimes very well described, there is not a sound basis for specifying these air flow rates and, to a certain extent, we know very little about the real ventilation needs.
There is almost no knowledge about the real health effects. The total exposure of people depends among other things on the source strength of pollutants in the room which vary in time and location. This is further complicated by the varying time that people spend indoors and outdoors. It is quite difficult to determine the dominating pollutant for each room in a building. The absolute highest level of

performance approach may be to define the maximum effect of pollutants on the health of people. Most existing standards require flow rates based on assumed pollutants and their acceptable levels of concentration. Since there is no clear relation with health, the required flow rates are in most cases based on maximum CO_2 levels. CO_2 is used as an indicator for indoor air quality since it is a respiratory product related to the metabolism of people. The assumption is that CO_2 is a good indicator for all other human effluents. Over recent years ASHRAE and CEN have given more attention to the fact that ventilation systems themselves are a source of indoor air pollution. Hence the ventilation requirements will comprise an amount for the persons in the room plus an amount based on the emissions from the building and ventilation system. Another approach is to ventilate for people and to control all other polluters by source control. This means that emissions from building material and other sources at maximum source strength countered by a minimum ventilation level may not exceed the allowable concentration level. In the Netherlands for instance this source control approach is applied in the Dutch Building Decree for several pollutants. At a ventilation level, which is 1/6th of the required level, these pollutants may not exceed their allowable concentrations. These different strategies in regulations and standards are completely due to the lack of knowledge on health effect and indoor air quality levels.

4.3 PRESENT SITUATION IN GUIDELINES, STANDARDS AND REGULATIONS

Ventilation standards throughout Europe but also worldwide differ considerably as well as the ways to express the ventilation target. In most cases however flow rates are specified. But even in that case it is not simple to compare standards. In some standards one will find flow rate based on per m^2 floor area while in others a certain flow rate per person is specified. In Figure 4 and Figure 5 standards and regulations are compared and recalculated in flow rate per person.

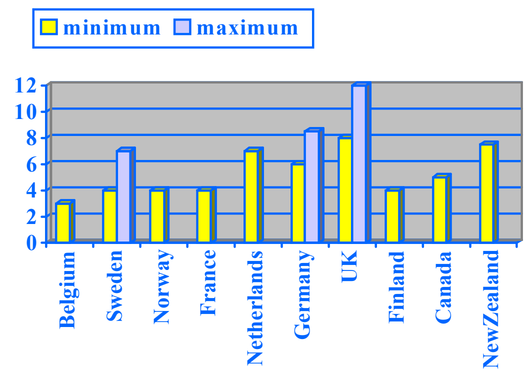


Figure 4 : Required flow rates per persons for dwellings (dm³/s)

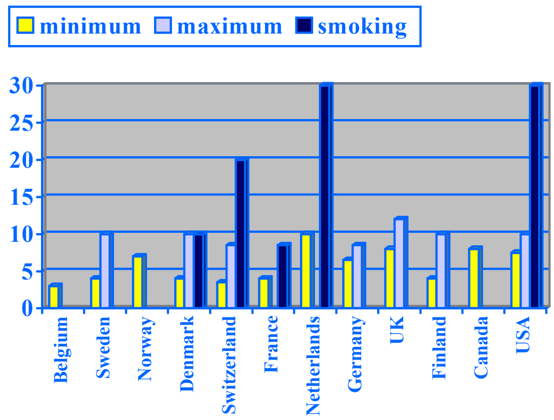


Figure 5 : Required flow rates per person for offices (dm³/s)

5 ENERGY USE DUE TO VENTILATION

5.1 INTRODUCTION

In the middle 90's, the buildings sector represented more than 40 % of the total energy consumption in the European Union (Energy in Europe, 1996). Although the energy efficiency of equipment is increasing, the number of new systems and appliances is also increasing, e.g., the demand for HVAC systems is fast increasing in many countries, especially in Southern Europe. So, energy consumption in the built environment still has a tendency to increase. Taking into account the EU energy policy and the Kyoto agreements, it is very important to identify energy saving opportunities in the buildings sector. After the effort to increase insulation in the past decades, it is clear that energy use due to air change is now the area with more potential for further savings. Orme (1998) estimated that, for the non-industrial building stock of the then 13 AIVC countries, the total annual energy needs for heating due to air change amounts to 48% of delivered space heating energy.

Regulations directly or indirectly concerning ventilation are now in force in most countries. These try to take in account both human health and energy consumption considerations. Qualitatively, the energy consumption and indoor air quality (IAQ) relate to ventilation rates as shown in Figure 6. Quantification of IAQ and health requirements, however, is not yet technically clear. For this and other reasons, different countries have adopted, for the same type of buildings, different minimum ventilation rates. Moreover, many regulations do not usually stimulate energy-efficient solutions. For example, most regulations do not require advanced strategies such as heat recovery and free-cooling. If the regulation of air flow rates has been used as a way to establish a compromise between energy and IAQ, there are other means available to decrease energy consumption without a penalty in IAQ, namely demand controlled ventilation, free-cooling and heat recovery.

Over this background, a study was developed to assess the impact of ventilation rates upon energy demand as well as the potential for energy savings resulting from the use of innovative technologies. This section presents a summary of this study along with associated conclusions.

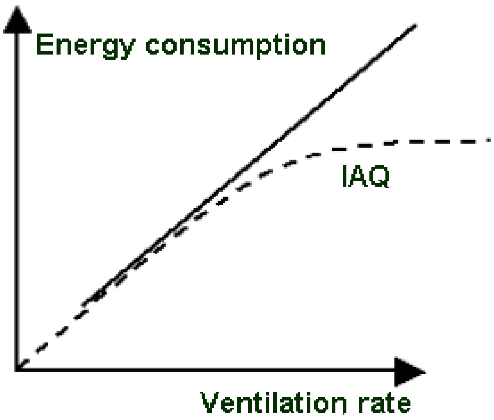
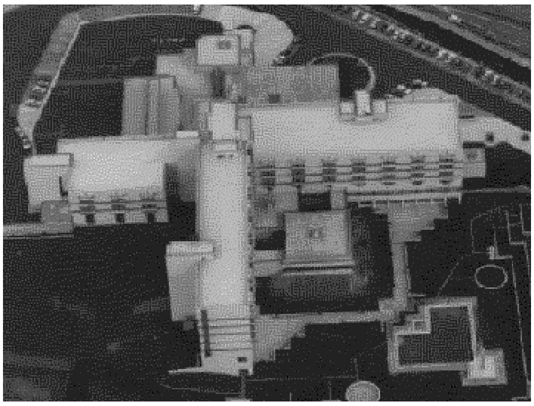


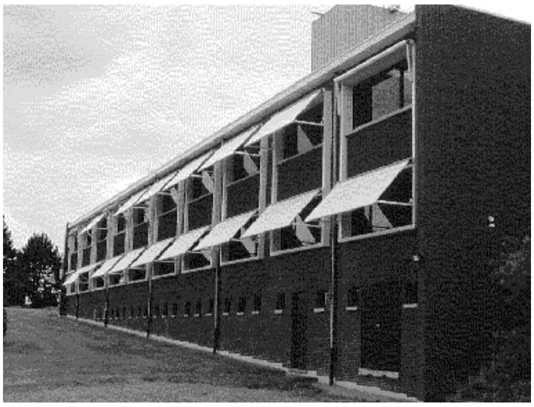
Figure 6 : Energy consumption and IAQ relation to ventilation rates

5.2 METHODS

The analysis consisted of a set of sensitivity studies performed by computer simulation. A set of case-studies was selected to represent the diversity of the built environment in Europe. Buildings selected were a hotel, a university auditorium, an office building, a semi-detached dwelling, an apartment and a large office building. These buildings can be seen in Figure 7.


Hotel (Portugal) (Leal et al, 2000) [Ref 16]


Apartment (The Netherlands) (Leal et al, 2000) [Ref 13]


Office building (Belgium) (Delmotte et al, 2000) [Ref 11]


Large Office Building (Portugal) (Leal et al, 2000) [Ref 17]


University auditorium (Portugal) (Leal et al, 2000) [Ref 14]


Semi-detached dwelling (The Netherlands) (Leal et al, 2000) [Ref 15]

Figure 7 : Case-study buildings at their original locations

Although the buildings are located at a specific place, it was decided to evaluate their energy requirements in a mild, a moderate and a cold climate. After a statistical study (Leal et al, 2000) [Ref 23] it was decided to consider Lisbon as the mild climate (hot in Summer), Uccle as the moderate climate and Stockholm as the cold climate. Each building was thus studied as if located at each of these three locations.

In order to make the simulations of a building in different climates realistic, they were adapted to the local construction practice and utilisation habits. To do so, local experts in each country provided typical values for each of the main characteristics of each building in their countries.

For most buildings, some measured data was available, thus allowing a calibration of the simulation model before performing any sensitivity studies. A good agreement was found in all cases.

Most of the simulations were performed with a well-validated, widely used software, the European reference program, ESP-r (ESRU, 1997). For some particular sensitivity studies where ESP-r is not particularly efficient, Visual

DOE (Eley Associates, 1996) and STEVE (Lima et al., 2000) have also been used. Although good agreement was found between simulation results and measured data, when available, conclusions from the BESTEST IEA project (Judkoff and Neymark, 1995) must always be kept in mind, especially those stating that all programs revealed modelling limitations, faulty algorithms and some differences in results.

Following the make-up of a calibrated model, sensitivity studies could be performed. These focused essentially on the analysis of the energy impact of the following issues:

- Ventilation rates stated by different regulations and standards;
- Ventilation control strategies, such as demand-controlled ventilation and free-cooling.
- Fan power consumption.
- Other issues such as heat recovery and building air tightness.

5.3 RESULTS

5.3.1 Impact of ventilation rates mandated by standards and regulations

The main reason for having ventilation requirements is human health and building conservation. However, clear, objective, uncontroversial and widely accepted criteria to define ventilation rates based solely on health considerations are still not available. Under these circumstances, each country defines ventilation rates taking into account different criteria. Assuming that the outdoor air quality is about uniform throughout European cities, it makes sense to ask why the ventilation rates stated by different regulations and standards are so different. There are several possible reasons for this:

- The typical finishing materials in the interior of buildings in different countries are not the same and thus have different pollution loads, requiring different ventilation rates.
- Some regulations can allow higher ventilation rates because they compensate with other measures, e.g., compulsive heat recovery or efficiency of the equipment and systems.
- Different cultural and political attitudes towards the energy consumption vs. IAQ balance.

If all those aspects are taken in account to study the energy impact of regulations and standards, a comparison between different regulations and standards becomes difficult to make and there is a risk of loosing clarity in the analysis of the results. So, in this approach, the study is made only in terms of the energy impact of ventilation rates mandated by standards and regulations. In future work, more integration can be attempted, but this present analysis could already provide some interesting results.
As an example, Table 1 shows how ventilation rates in the hotel change from country to country, which, in turn, raises the question of how they impact upon energy demand.

Country	Criteria
Belgium	Bedroom : 3.6 m³/h.m² (min. 25 m³/h, max. 36 m³/h per person) Bathroom : 3.6 m³/h.m² (min : 50 m³/h) (max: 75 m³/h)
Portugal	35 m^3/hr per person
Sweden	Minimum 0.35 l/sm² and minimum 15 l/s in guest rooms, 7 l/s.person
France	25 m^3/h per person
UK	with no smoking: 8 l/s/person with some smoking: 16 l/s/person with heavy smoking: 24 l/s/person with very heavy smoking: 32 l/s/person
Switzerland	Smoking not allowed: 12-15 m^3/h.person (0.15 % CO2) 25-30 m^3/h.person (0.10 % CO2) Smoking allowed: 30-70 m^3/h.person

Table 1 : Criteria for defining ventilation rates in different countries for the hotel

This study investigated what would happen if the mechanical ventilation rates for some buildings in a particular location were changed to those mandated by other countries' regulations. Figure 8 shows the heating and cooling energy demand for a hotel located in Portugal when applying the air-flow rates required by different regulations and standards. It shows that the difference between the lowest and the highest heating energy demand is 90 %. If the hotel were really located in Belgium or in Sweden, this maximum difference would still be 70% and 82% respectively. CEN CR 1752 (class A) and ASHRAE 62-1989 results are also presented.

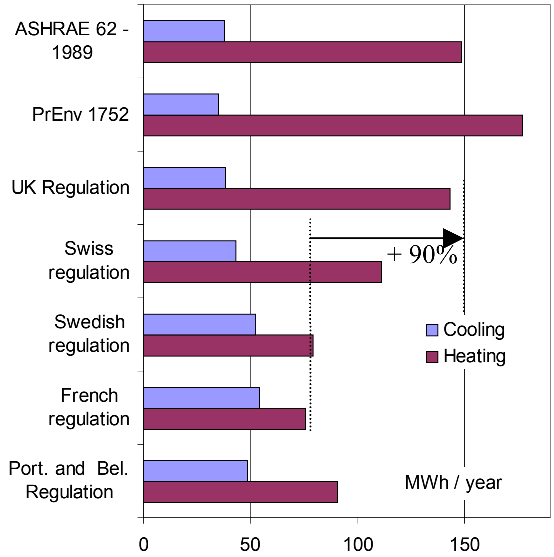


***Figure 8** : **Energy demand of the hotel in Portugal applying ventilation rates stated by different regulations or standards**[1]*

Table 2 shows the same type of results for this hotel and for the other buildings studied. It can be confirmed that the ventilation rates stated in regulations and standards can have a large impact upon heating energy demand. It also shows that the current differences of ventilation rates in European regulations and standards have important consequences in terms of energy demand.
The effect upon cooling can also be seen, although it goes in the opposite direction: increasing ventilation rates decreases cooling energy demand. In effect, this is equivalent to reducing free-cooling, which will be shown in the next section to be a desirable option everywhere. This inverse behaviour of heating and cooling energy demand thus suggests that a good system must always allow the possibility to control the ventilation rate, providing a certain minimum for IAQ control in Winter but allowing it to increase when this is beneficial in Summer.

5.3.2 Impact of Control Strategies

One of the good principles of ventilation design should be to provide air "where needed, when needed" and not more than necessary. Unfortunately, most installed systems still provide a constant ventilation rate, assuming that the maximum number of people is always present in the ventilated room.

[1] In the UK regulation, the ventilation rate depends on whether smoking is allowed or not. In the hotel, smoking was considered allowed, but not allowed in the school auditorium.

In section 5.3.1 it was seen that, on average, the cooling energy consumption decreases with the increase of ventilation rates. The correct way to take advantage of this effect is to increase the ventilation rate when the outside air temperature (or enthalpy) is lower than the indoor temperature (or enthalpy), i.e., to use "free-cooling". However, to take advantage of this, the system needs to have special components and an appropriate control, which usually are not installed to reduce investment costs.
Figure 9 shows the impact of having demand-controlled ventilation, i.e., ventilation proportional to the number of people actually present in a room, and free-cooling upon heating and cooling energy demand. The same type of data were obtained for other buildings. Values vary depending upon each specific case, but the main conclusions are in line with qualitative expectations:

- Demand controlled ventilation has a potential that is as high as the variation of the occupancy during the day;
- Free-cooling provides an effective way to decrease the cooling demand, for all types of climates, although it is only economically viable in buildings with high cooling demand.

	Minimum ventilation rates in reg. & standards l/(s.person)		**Heating energy demand** (MWh/year)			
	Lowest (A)	**Highest (B)**	**Virtual location**	**(A)**	**(B)**	**Difference between (A) and (B)**
Hotel	7	10	Portugal	76	143	+ 90%
			Belgium	210	357	+ 70%
			Sweden	278	506	+ 82%
Audito-rium	5	10	Portugal	1.5	3.5	+128 %
			Belgium	6.5	11.8	+81 %
			Sweden	12.1	19.6	+62 %
Dwel-ling	a)	a)	Portugal	1.6	3.9	+ 152%
			Belgium	6.7	12.0	+ 79%
			Sweden	6.9	20.2	+ 193%
Large Office building	7	10	Portugal	111	182	+ 64%
			Belgium	427	612	+ 43%
			Sweden	543	789	+ 45%

a) ventilation criteria could not be expressed in these units. Some were expressed in terms of flow/area, while other were just dependent of the type of room.

Table 2: Minimum ventilation rates and impact upon heating energy demand

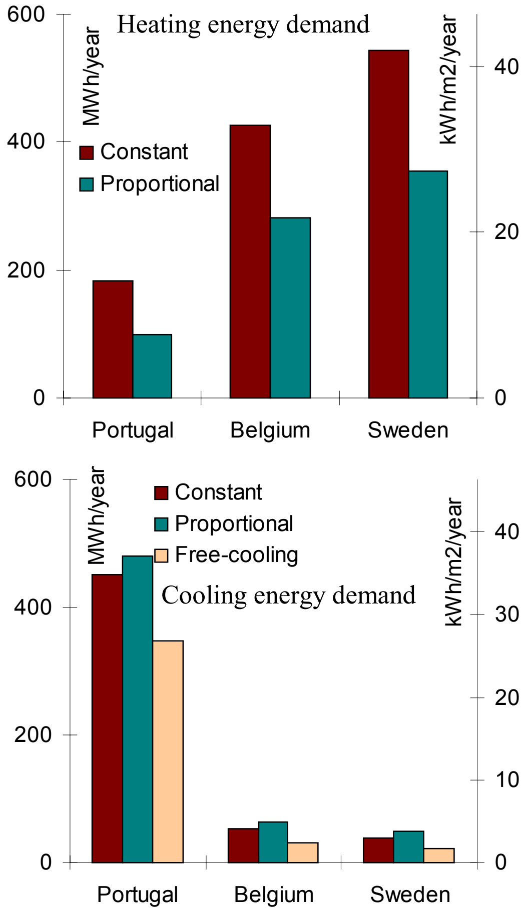


***Figure 9** : Heating and cooling energy demand of the large office building as a function of the control strategy, for different virtual locations.*

5.3.3 Importance of Fan-Power Consumption

The range of specific fan power consumption (SFP) in existing and even in new buildings seems to be very large. The specific fan power consumption values in existing and in newly designed buildings vary between 5.5 and 13 W/(l/s), while a good system can have about 1.0 W/(l/s) and a very good one can go as low as 0.5 W/(l/s) (Blomsterberg et al, 2000) [Ref 5]. Of course the SFP doesn't only depend on the fan itself but also on the duct design, diffuser selection, etc.

Table 3 shows the fan power consumption and its weight in total HVAC energy consumption (electricity equivalent, assuming COP 3.5 for refrigeration system) for three scenarios of SFP in the large office building . This is a building with 100% fresh air, i.e., without recirculation. Heating and cooling loads are removed by fan-coils. It is observed that, with a good SFP, the energy consumption by fans can be kept below 15% of total HVAC energy, but with a bad system it can represent more than 50 % of HVAC energy consumption. Of course, in all-air systems with recirculation, these values can be much higher.

The results thus show that care taken in the design of ducts and specification and selection of fans is of utmost importance.

5.3.4 Impact of Heat Recovery

The consequences of heat recovery were also studied. Taking a simple 50% efficiency, results showed a saving potential in heating energy demand of up to 40% in the hotel (in Portugal), 50% in the auditorium (in Belgium), 20% in the dwelling (in Stockholm) and 38% in the large office building (in Portugal). All these buildings have mechanical ventilation systems that centralise exhaust. They also pressurise the building, in practice eliminating infiltration.

	Portugal	Belgium	Sweden
Heating	182	427	543
Cooling	129	15	11
Fans (Good, FSP=1 W/(l/s))	56	56	56
	15%	11%	9%
Fans (average, FSP=5 W/(l/s))	279	279	279
	47%	39%	34%
Fans (bad, FSP=10 W/(l/s))	560	560	560
	64%	56%	50%

Table 3 : Energy consumption in MWh/year and Fan power portion of HVAC energy consumption for the large office building (10 l/s.person, constant flow, 100% new air)

5.3.5 Integrated impact of the best technologies

The effects of a series of variables have been considered individually in the previous sections. Now we compare the "common system" and the "best system", taking the large office building as the selected case-study. Table 4 lists the main assumptions made for each of the cases and Table 5 indicates the results, in terms of energy consumption (electric equivalent, COP 3.5 for refrigeration system). The study shows that the "best system" can allow an energy saving larger than 60%.

Of course, the best system is also more expensive in terms of first cost (investment). The selection of the best case should be made on the basis of life-cycle cost (Blomsterberg, 2000) [Ref 6] or, at least, in terms of payback periods.

Table 6 shows the maximum investment cost acceptable for each of these technologies, for the same building, if the maximum payback period acceptable is set to be 7 years (interest rate assumed as 4%, and inflation assumed as 2%).

	Common system	**Best system**
Ventilation rate & control	10 l/s.p constant	10 l/s.p proportional
Free-cooling	No	Enthalpy control
Heat Recovery	No	heat rec. 80% efficiency
Specific fan power Consumption	5 W/(l/s)	1 W/(l/s)

Table 4 : Main properties of "common system" and "best system"

	Portugal		
	Common	*best*	*saving*
heating	182	61	67%
cooling	129	91	29%
fans	279	38	86%
total	590	190	68%
	Belgium		
	Com.	*best*	*saving*
heating	612	277	55%
cooling	12	9	30%
fans	279	47	83%
total	903	333	63%
	Sweden		
	Com.	*best*	*saving*
heating	789	340	57%
cooling	9	7	27%
fans	280	47	83%
total	1078	394	63%

Table 5 : Energy consumption for "common system" and "best system", MWh/year

	Portugal	**Belgium**	**Sweden**
Heat recovery	19.4	30.7	43.2
CO_2 control	19.6	33.2	43.6
Free-cooling	21.5	8.8	6.9
All	62.1	66.1	83.0

Table 6 : Maximum acceptable investment for several energy-efficient technologies for the large office building, assuming a payback period of 7 years (in k€).

So, ventilation regulations should be critically evaluated to ensure sufficiently good IAQ and energy efficiency at the same time. Good regulations should go much further than just specifying minimum ventilation rates. They should be performance based and promote the use of efficient ventilation techniques, i.e., variable ventilation, free-cooling and heat recovery.

5.4 CONCLUSIONS

Ventilation rates mandated by standards and regulations can have a very large impact upon the energy consumption in a building. If ventilation rates mandated by regulations and standards from different countries are applied to a certain building at a certain location, differences of nearly 100 % in cooling and heating energy demands can be found. As minimum ventilation rates should be established based on health criteria, these results call for a critical evaluation of the existing standards and regulations towards a certain degree of uniformity.

The use of control procedures that allow variable ventilation rates in response to the real and time-dependent occupancy can have an extremely important impact on energy consumption. This is especially applicable for service buildings with a highly variable occupation pattern during the day. The energy saving potential for this technique can be significantly larger than the savings potential for heat recovery. This is thus an area with great potential for development. Regulations and standards should clearly make a reference to this issue and promote this type of techniques.

In general, heating energy consumption is proportional to ventilation rates, but cooling consumption increases if ventilation rates are smaller. In Summer, the optimum ventilation pattern is low ventilation rates when the outdoor temperature is high and large ventilation rates otherwise, i.e., free-cooling.

Energy consumption due to fans can be usually small in the total HVAC energy consumption if good design and specification take place, representing up to 15% of total HVAC needs, but, in some particularly badly designed cases, it can easily exceed 50% of total consumption. Electricity to run the fans is usually an expensive form of energy, and it should thus be reduced through a careful selection of components and careful design.

6 VENTILATION PERFORMANCES IN DAILY PRACTICE

6.1 REQUIREMENTS FOR VENTILATION SYSTEMS

6.1.1 Introduction

During the past decades a variety of means have been used to achieve improved levels of energy conservation, indoor air quality and safety within the building environment. One such method has been to define requirements to be introduced in building regulations and standards to steer developments in the ventilation market.

Standards and regulations can be a very good tool to create a building environment with a quality level which satisfies the needs of the users (requirements for quality) and the needs of the community (requirements of society).

Definitions [Ref. 27]

A building **code** or **regulation** is a binding document which contains legislative, regulatory or administrative rules and which is adopted and published by a government authority. As an example, requirements for ventilation systems will be specified in the building regulation.

A **standard** is a technical specification or other document available to the public, drawn up with the co-operation and consensus of all interests affected by it based on the consolidated results of science, technology and experience. It is approved by a body recognised on the national, regional or international level. A standard expresses agreed calculation procedures or test methods. In some cases it may include "hidden requirements".

A **guideline** is a document that can include everything as a standard can, however it recommends rather than requires.

A **code of practice** recommends solutions accepted by the technical community.

6.1.2 Objectives

The analysis aims to evaluate the present situation regarding the impact of building regulations and standards on

- the performance of ventilation systems and
- the development and market entry of smart systems and components

At the same time a picture of the situation in the countries directly or indirectly participating in the *TIP-Vent* project is obtained. (Filleux et al, 2000) [Ref 12]

6.1.3 Approach

A combined two step approach has been adopted: In a first step the stringency level of a singular **standardised topic** has been studied. The qualification used in this study is „stringent", „poor regulation" and „lack of encouragement or no regulation". In a second step the relevance to the **performance criteria** has been evaluated. Combining the results of both steps the average European level of impact of a singular standardised topic on the performance is obtained. The impact is expressed by a rating for each performance criteria

In the frame of the *TIP-Vent* analysis the most impacting, common and promising topics that are standardised in the various countries are:

Standardised topics
Heat loss
Heat recovery
Heat consumption
Electricity consumption
Prohibition of electric appliances
Cooling demand proof

IAQ
Air change rate
Ventilation (air flow) rate
Velocity and turbulence
Indoor air temperature
Acoustic level
Air change efficiency
Air tightness
Fire protection

System efficiency
Fan efficiency
Efficiency of components

Velocity in ducts
Pressure drop
Duct leakage

The following **performance criteria** were used to evaluate the impact of building regulations and standards on the performance of ventilation systems:

- Energy consumption (thermal and electrical)
- Comfort (indoor air quality, thermal comfort, noise level)
- Costs (investment costs, maintenance costs)

The performance criteria used are restricted to the operation phase of the ventilation systems.

Where possible building regulations and standards in the participating countries have been compared. However in many cases, due to the diversity of regulatory mechanisms and differing ways to express the ventilation target in the different countries, the task proved to be difficult.

6.1.4 Standards and regulations in the various countries

European standards

CEN is the body responsible for the planning, development and adoption of European standards. The principle deliverable of CEN is the European Standard (EN).

Harmonisation

Up to now harmonisation activities took place in the field of calculation procedures and test methods. Differences in regulatory mechanisms methods of expression of requirements has been the main obstacle of further harmonisation.

National standards and regulations

Figures 10 and 11 depict the difference of regulatory mechanisms in the Netherlands and Switzerland. Whereas a distinct separation between requirements, test methods and recommended solutions exists in the Netherlands, the Swiss Norm (SIA V382) [Ref 38] contains requirements, test methods, calculation procedures all in one and also provides solutions. According to the CEN standstill agreement SIA V382 remains a temporary norm during the preparation of the corresponding EN.

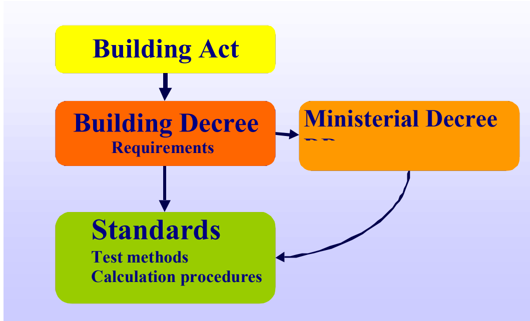


Figure 10: Building regulations in the Netherlands

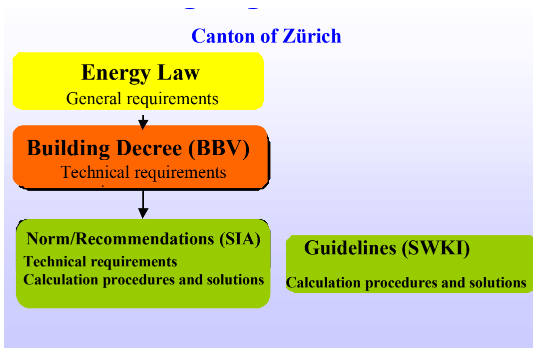


Figure 11: Building regulations in Switzerland

6.1.5 Impacts on the performance of ventilation systems

Figure 12 shows the relevance of the different standardised topics in the countries considered. The bars give the number of countries concerned by the topic, the rating expresses the impact on the performance averaged over the different countries.

A high rating means that the topic is regulated on a high stringency level in several countries and that the fulfilling of the performance criteria is good. More than twenty standardised topics have been analysed in this manner.

High ratings were obtained for requirements regarding the thermal heat loss, the ventilation rate, the indoor air quality, the indoor air temperature, the noise level and the fire protection.

Low ratings were obtained for requirements regarding the efficiency of systems and components. These are air change efficiency, pollutant removal efficiency, overall system efficiency and fan efficiency.

Conflict in the analysis arises when the impact of a given standardised topic gives contradictory results for the different performance criteria. As an example, a conflict arises between increasing the ventilation rate to reduce pollutant and cooling loads, or reducing the ventilation rate in order to minimise heating loads and reduce discomfort.

Requirements in building regulations and standards tend to increase investment costs and maintenance costs. This cost effect seems not only to be caused by the standards themselves but also by the public's acceptance of higher costs for higher comfort levels.

The country by country analysis showed that the most stringent requirements on air tightness and heat loss are imposed by countries subjected to cold climates. The ventilation rates mandated by standards and regulations in the different countries are different, and therefore also their impact on heating and cooling loads.

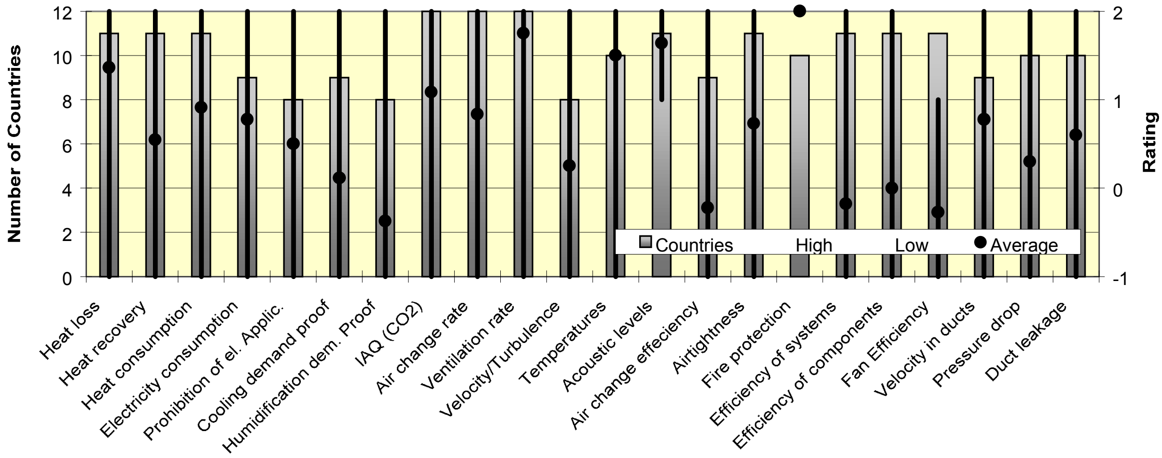


Figure 12: Impacts of standards and regulations on the performance of ventilation systems

Number of countries concerned: bars and left hand scale
Rating: dots and right hand scale

6.1.6 Impacts on the development and market entry of innovative systems and components

The impacts on the development and market entry of systems and components has been analysed and rated separately country by country. Large differences exist, even within the countries themselves (regional markets). Nevertheless, drivers and barriers have been identified. Regarding the barriers it is important to distinguish between technical and institutional barriers.

Figure 13 shows the impact of the different standardised topics on the development of systems and components. The bars give the number of countries concerned by the topic, the rating expresses the impact averaged over the different countries.

Ventilation in dwellings, heat exchangers, silencers, efficient fans and IAQ-controls are among the most cited systems and components which have been positively influenced by the standards and regulations.

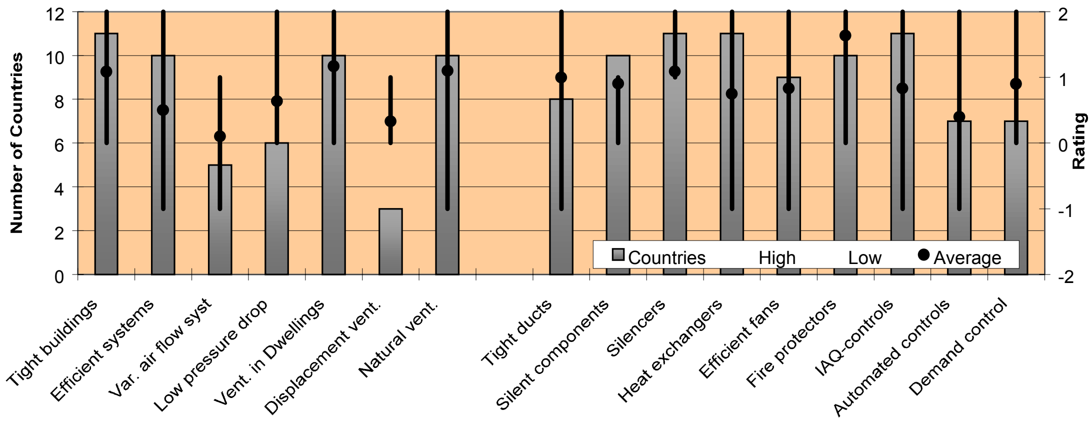


Figure 13: Impacts on the development of systems and components

Number of countries with impact: bars and scale on left hand side
Rating of impact: Dots and scale on the right hand side

6.1.7 Drivers and barriers

Drivers of high priority for the development of systems and their components and therefore strong fields of present and future activities are comfort requirements (acoustics and indoor air quality) and energy issues (efficiency, heat recovery, air tightness and duct tightness).

Drivers of lower priority for the development of systems are requirements regarding variable air flow and demand control. If introduced in advanced standards these fields can be very interesting for future developments.

Institutional barriers were encountered where "no regulation" or "lack of encouragement" has been found. Lack of encouragement is hindering development and application of efficient components and systems in some countries.

Generally, more demanding standards tend to stimulate rather than to hinder the development of new concepts and components.

6.1.8 Future developments

The following fields for future activities have been identified:

Fields for future activities

- Need for improvement of efficiency of systems and components
- Solutions for low pressure drop systems
- Integration of displacement ventilation and variable air flow systems in the system design
- More stringent enforcement and site checking inspections
- Strong need for education of installers and inspectors.
- Introduction of LCA (Life Cycle Analysis in the development of new components

Comments

Requirements on noise level, energy efficiency, good pressure conditions and air quality have been the motor for the development of smart components within the *TIP-Vent* project (see chapter 9).

Traditionally, means of enforcement are the building permission, inspections, warranties and product liability.
In the past decade requirements on site checking have successfully been introduced in northern countries and are responsible for the improvement of the performance of ventilation systems. In many countries however site checks are still felt to be costly procedures, although they can help the contractor and owner to find the optimum operational parameters of the ventilation system.

Standards are tending to become more performance oriented rather than requiring specific solutions (i.e. being descriptive). Parallel to this development the process of harmonisation of the European standards is still in progress.

Finally better education and efficient enforcement with handover and site-checking inspections on a regular basis should improve the compliance of the building practice with the standards significantly.

6.2 CURRENT DESIGN PROCEDURES

A simplified questionnaire was employed in order to obtain information relating to ventilation design procedures in a range of European countries (Blomsterberg et al, 2000) [Ref 5]. It was assumed that traditional design procedure applies to competent designers, i.e., those who are able to produce good designs that meet or surpass initial expectations. This excludes explicitly those who simply get a building design from the architect, make no load calculations except some rough rule of thumb, and proceed with a totally empirical design that may or may not be the most suitable for the particular application. This latter mode would be the most common method for the low-end of the market i.e. small installers responding directly to the orders of individual clients without the intervention of an HVAC designer, or to an architect in a small project (e. g. a residence or a small office) not involving any HVAC engineer.

6.2.1 Description of procedures

For most residential buildings in the participating countries the current traditional design of ventilation systems is mostly based on the size of the building, number of rooms and usage of the rooms. For most commercial buildings the planned activity in the building and in the individual rooms are also taken into account i.e. air flow rates in l/(s person) and l/(sm^2). Air flow rates are determined from building regulations or informal standards. For a commercial building the need for a mechanical cooling system is determined i.e. whether air conditioning or comfort cooling is required or not. A system is chosen based on a combination of experience, rules of thumb, handbooks and/or catalogues from manufacturers. The sizing of the system is based on design programs from manufacturers and/or typical values for air velocities and pressure drops. Pressure drop calculations including choice of air terminal devices are made using computer software and/or rules of thumbs, but for commercial buildings seldom only hand calculations. Sometimes the noise levels are estimated for residential buildings, using data from manufacturers or calculation programs from manufacturers. For commercial buildings this is always the case. In Switzerland and Sweden sound requirements exist. Drawings are made using CAD-programs for commercial buildings or still very often by hand for residential buildings. The smaller the building the simpler the design procedure usually is.

Energy conservation usually has a low priority among HVAC-designers in most countries, during the design of a ventilation system. The building code and/or standard requirements, which differ from country to country, are of course taken into account e. g. in Sweden the required 50 % reduction of the energy use for heating the ventilation air if heating is not based on renewables. In Switzerland a general energy concept is usually developed.

The use of electricity for mechanical ventilation is seldom taken into account by HVAC-designers. In Switzerland it is usually included in the general energy concept. For commercial buildings in the Netherlands it is taken into consideration, and in Sweden and France gradually becoming an issue of concern. In most other countries the use of electricity for ventilation is seldom an issue of concern.

Indoor air quality is gradually becoming an issue of concern, but separate calculations are seldom carried out. The indoor air quality is taken into account to the extent that in regulations and standards required or recommended air flow rates are fulfilled.

Rules of thumb relating to ventilation systems are widely used. These are primarily intended to assist in the initial design, but are in practise used much wider. A typical rule of thumb in most participating countries when designing a ventilation system is the air flow rate as l/(s and person) and/or l/(s and m² of floor area). Another rule of thumb is a certain range of air velocity in ducts. In some countries the space requirements for the ventilation system is based on experience e. g. area of fan room as a function of air flow rate. Often assumptions are made as to pressure drop across air terminal devices and pressure drop in ducts.

In addition to national building regulations and national and international standards, the designers use a relatively wide range of guidance material. There are guidelines based on experience from different organisations e.g. from manufacturers and suppliers of building services plants, professional organisations, research institutes, testing laboratories. The guidelines range from catalogues or CD-roms from manufacturers to detailed handbooks from professional organisations.

Design tools typically consist of calculation sheets and computer tools for standardised calculations supplied either by equipment manufacturers or independent software vendors and specific design guidance supplied by manufacturers (recommendations, diagrams, tables, etc.).

A wide range of computer software is available. Generic examples are given here:

- Air flow (single zone or multi zone network models giving the possibility to include infiltration, not very often used)
- Acoustics
- Building heat transfer (simplified energy calculation and dynamic energy simulation models)
- CAD
- CFD (determining air flows and temperatures e.g. within individual rooms)
- Duct/diffuser sizing (often from manufacturers)
- Heating and cooling
- Psychrometric design

All of the above generic software except CAD and CFD are used at times in the design of commercial buildings. CAD is regularly used for commercial buildings. In Sweden and Switzerland drawings for residential buildings are also fairly often produced using CAD-programs. The use of CFD tends to be restricted to larger and/or more complex designs e. g. large enclosures like atria, which warrant the additional time and expenditure involved. Air flow simulations are rarely made. The simplified energy calculations are sometimes carried out.

6.2.2 Conclusions

The current traditional design procedure for residential and commercial buildings is not really performance oriented and therefore does usually not give encouragement to implement innovative ventilation systems. It does, however, more and more encourage the installation of mechanical ventilation systems, also in residential buildings. The procedure probably does at least not prevent the implementation of innovative systems in commercial buildings.

Energy use usually has a low priority among HVAC-designers in most countries when designing a ventilation system in residential and commercial buildings. This is often due to the lack of life cycle perspective, instead the investment cost is considered first of all. The energy requirements in the building code, which differ from country to country, are of course taken into account.

Use of electricity for mechanical ventilation is only taken into account in a few countries.

Usually the indoor air quality is taken into consideration to the extent that in regulations and standards required or recommended air flow rates are fulfilled. Indoor air quality is gradually becoming an issue of great concern.

The wide use of rules of thumb means that mostly conventional ventilation systems will be implemented. What is considered to be a conventional system will of course differ from country to country and change over time.

The wide range of guidance material, tools and computer tools used for the design of ventilation systems may or may not encourage the implementation of innovative ventilation systems.

The wide range of computer software, available for the design of ventilation systems for commercial buildings, is likely to encourage the implementation of innovative ventilation systems, as a better understanding of systems can be reached.

Often a client will give the task of designing a ventilation system to the HVAC engineering firm, who offers to do the job for the lowest price. This usually excludes thorough analysis using e.g. advanced computer software and LCC (life cycle cost)-analysis, and thereby the implementation of innovative ventilation systems.

There are many ways of encouraging well performing ventilation systems and the implementation of innovative ventilation systems for this purpose: regulations, additional financial support, education/information and market forces. In order to facilitate the implementation, a more performance oriented approach to ventilation has to be developed and implemented (see chapter 7 🗎).

6.3 EXAMPLES OF SYSTEM PERFORMANCES

6.3.1 General

The objective of this chapter is to give a clear picture of the in situ performances of mechanical ventilation systems.
This will include aspects such as air flow rates, control strategies, fan power, acoustical performances, draught problems, heat recovery efficiency, IAQ, cleanliness and some building characteristics e.g. air tightness. The main focus will be on airflow rates since practice show that 90 % of the failures are devoted to airflow rate.

6.3.2 Air flow rates

Although flow rates are not really a performance oriented approach most requirements on ventilation in regulations and standards are specified as flow rates. Limiting the concentration of the existing pollutants in buildings is a more performance oriented approach. This however means a definition of all possible indoor pollutants and their acceptable indoor air concentration limits.
In practice a wide variation of air flows can be found. In Figure 14 one can observe a wide spread measured in 33 Finnish office buildings (x-axis). The lines through the average value covers 25% to 75% of the flowrates. The difference between the lowest and the highest value is an order of magnitude, so more than a factor of 10 difference.
Even taking into account a range of required flow rates per m^2 in the regulations and standards from 0.5 to 1.5 $dm^3/s.m^2$, half of the Finnish buildings are outside this range.

Another example is the Swedish ELIB study [Ref 37]. Measurements took place in a few thousand dwellings. As can be seen from the results in Figure 15 the bulk of the measured data is lower than the prescribed minimum. This was one of the reasons to start an inspection program. (OVK) [Ref 40].

The example from Belgium [Ref 29] shown in Figure 16, delivers again a wide spread in results. Looking to the toilets most of them have too high a ventilation rate compared with the Belgian ventilation standard, while bathrooms in this example have mainly too low ventilation.
So although in practice airflow rates are in most cases too low, sometimes they are also too high. Too low flow rates may cause IAQ and related health problems. Too high flow rates may cause problems with comfort and have an important negative effect on the energy consumption of buildings.

6.3.3 Ductwork

6.3.3.1 *Metal ducting*

The duct leakage measured in Belgian and French buildings was about 20 % of the nominal air flow rate.
In France and Belgium most duct systems did not reach the class A requirement from the draft CEN Standard (prEN 12237) [Ref 31], while in Sweden due to inspection procedures, better workmanship and better products almost all systems fulfil the class B requirement (Figure 17) [Ref 30].

6.3.3.2 *Concrete ductwork*

Contrary to what one might expect, concrete ductwork may be also quite airtight.
Sometimes in case of retrofitting this is done by a plastic coating or lining on the inside of the duct. But even newly manufactured “floor storey high” concrete ducts may reach class B. This can only be realised when they are constructed in an industrial environment and moreover assembled on site by good craftsmen.

6.3.4 IAQ levels

The indoor air quality is often expressed in terms of CO_2 concentration. CO_2 itself is not an important contaminant but it is used as an indicator for human effluents.
The CO_2 data from measurements in 30 Dutch dwellings can be found in Figure 18. The results reported here are from a study carried out in three groups of 10 dwellings with practically the same floor plan. Each group had a different ventilation system. The ventilation systems are:

- Natural supply and passive stacks (natural)
- Natural supply with mechanical exhaust (mech. exhaust)
- Mechanical supply and exhaust (balanced)

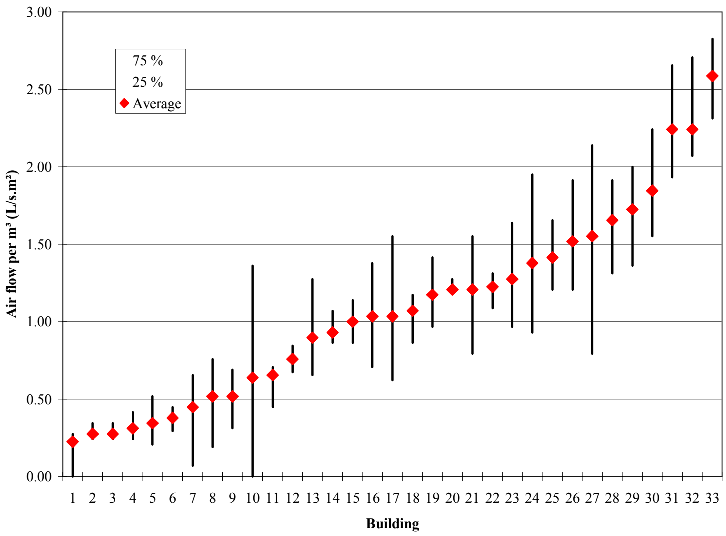


Figure 14 : Overview of measured air flow rates at room level in 33 Finnish office buildings (source : Seppanen)

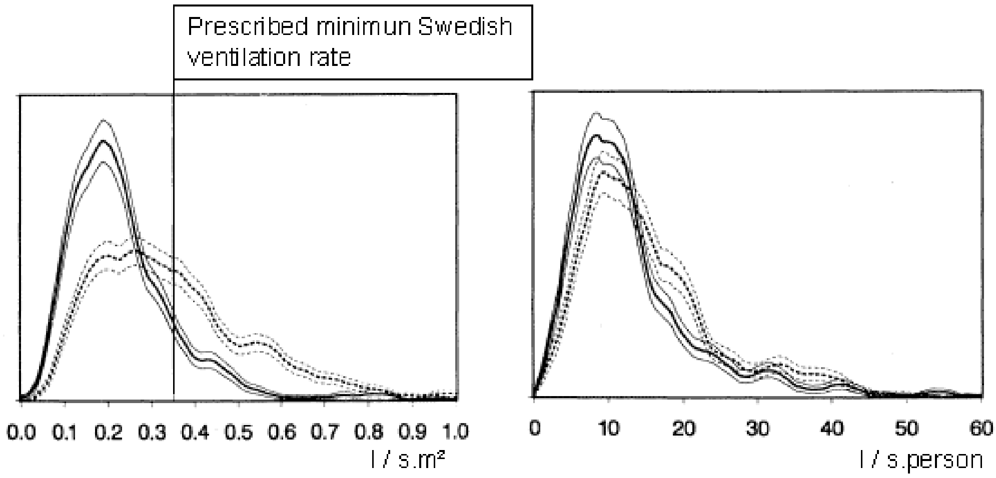


Figure 15 : Ventilation in single-family houses (unbroken line) and multi-family buildings (dotted line) [Ref 37]

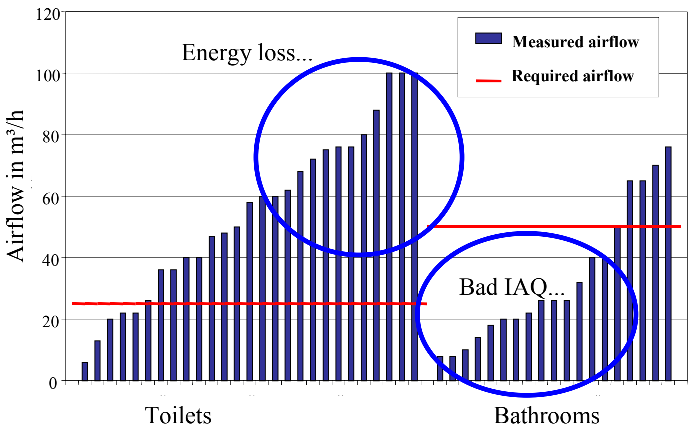


Figure 16 : Results from Belgian SENVIVV study [Ref 29]

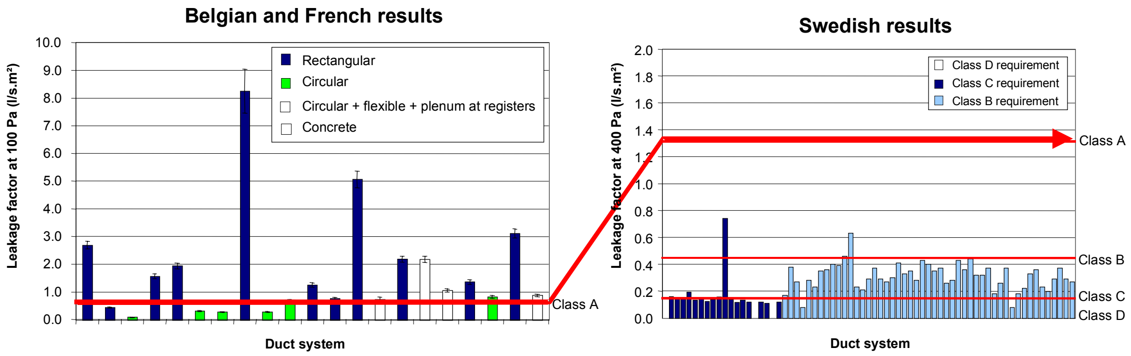


Figure 17 : Duct leakage in real buildings in Belgium, France and Sweden (SAVEDUCT) [Ref 30]

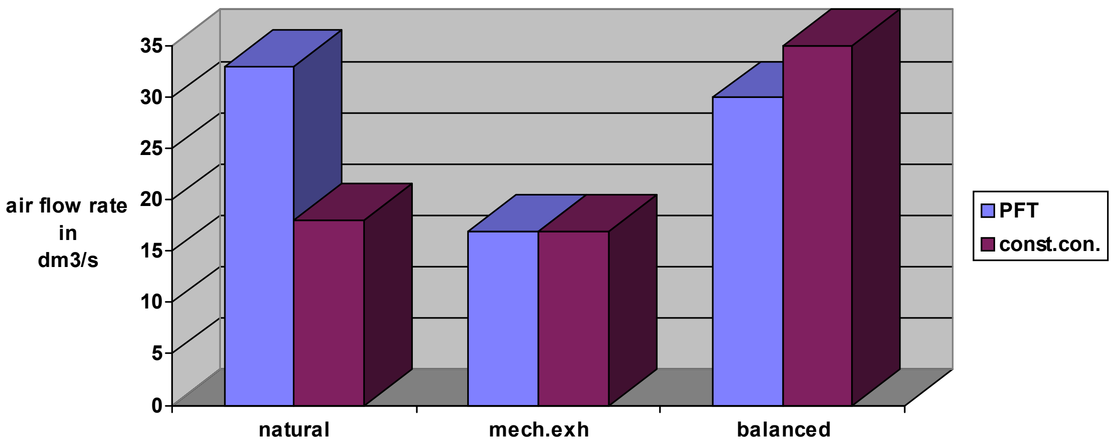


Figure 18 : Measured air flow rates in 30 Dutch dwellings

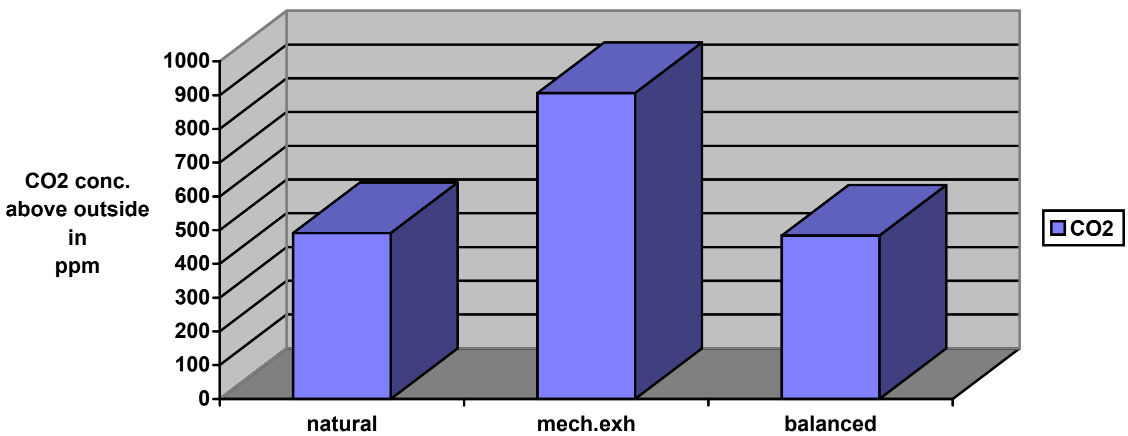


Figure 19 : Measured CO_2 data in 30 Dutch dwellings

The CO_2 concentration in the dwellings with the mechanical exhaust system is much higher than in the two other systems. This is due to the higher occupancy, better air tightness and a lower air flow rate. The lower flow rate is mainly due to the use of the ventilation system.(see also Figure 19)

So the interpretation of measured data is not easy. Explanations for certain effects only can be given if you have knowledge of a number of parameters determining the indoor air quality such as: building air tightness, the use of the building, the number of people in the building, the way they use their ventilation provisions etc.

6.3.5 Fan Power

Fan power for good designs ranges in non residential buildings typically from 1 – 5 W/(dm^3/s) (see also § 5.3.3) .In task 5.2 of the *TIP-Vent* project the energy for fans used in domestic ventilation 0.5 W/(dm^3/s) was used as a reference situation (Bulsing, 2000) [Ref 7]. The improvements made are around a factor of 3 so the fan power was reduced to 0.15 W/(dm^3/s).

6.3.6 Comfort

Comfort is depending on many variables. In fact the ventilation system may not disturb the comfort in a room. But to reach good comfort not only fresh air is required but also the right temperature of the air. In Table 7 based on measurement results of IEA Annex 27 is given.

Example:
If you have a top hung window, size 60 x 20 cm, which can be opened and controlled at about 60 cm^2. This opening is considered as horizontal supply in high position with low induction. At an outside temperature of 5 ^oC , the table gives a +, which means that 85 – 95 % of the occupied space in the room give comfortable conditions.

6.3.7 Control

Most natural air inlets are manually controllable. The control on these inlets is far from optimal. Good control possibilities are crucial to reach acceptable indoor air quality levels in buildings. Natural supply openings mainly fail on control. For a fixed position of an air inlet due to fluctuations of wind the airflow rate through the inlet is varying. This variation causes often draught problems. A solution for that is so called self-regulating inlets. These products deliver a constant airflow regardless of the pressure difference across it. Two examples namely a passive and an active solution are presented (Figure 20).
The passive controlled air inlet is in fact a vane balancing on a support. In case wind enters from the right side, the vane (1) is tilted to another position.
The active inlet consists of a motor which controls the position of the slider which closes or opens the grill.

Further more a coupling of the control on inlets should be coupled to the control of the outlet. This is because otherwise the imbalance will cause draft problems and unnecessary energy use.

6.3.8 Sound pressure levels

Sound pressure levels from ventilation systems are often not at acceptable levels. This is usually due to a lack of adjustment and commissioning of the ventilation system components. In cases where the fan causes the sound problems the only solution may be sound attenuation.

6.3.9 Performances during operation

6.3.9.1 General

The performance during operation is in many cases very bad. There is a lack of maintenance and cleaning. Dust, particles and grease in ductwork and at air terminal devices will lead to a decrease of the flow rates. Moreover all kinds of instructions for the users are missing in practice. Some control systems work so poorly that after a while, those responsible for running the system simply switch off all automatic control functions. To improve this situation a general accepted procedure for checking systems is necessary. A new European standard is in preparation.

6.3.9.2 OVK procedure

Sweden is the only country in the world where performance checking of ventilation systems is obligatory. They developed the so-called OVK procedure (Obligatorisk Ventilations-Kontroll). In essence this means that ventilation systems in buildings have to be checked regularly. The inspection intervals are different depending on the type of buildings and type of ventilation system. Even the type of inspector is specified. K means a special qualified inspector. N a normal educated inspector (*Table 8*) [Ref 40].

When the requirements during checking are not fulfilled, measures have to be taken in a specified time to correct the situation.

Type of ventilation opening		Outside temperature in ^{0}C						
General	Specific	-15	-10	-5	0	5	10	15
High induction	direction supply upwards	-	-	0	+	++	++	++
	Circular opening, radial flow direction	--	--	-	-	0	++	++
	horizontal supply	--	--	--	--	-	+	++
Low induction or windows ajar	horizontal supply high position	--	-	-	0	+	+	++
	vertical opening medium position	--	--	--	--	--	-	-
	horizontal opening low position	--	--	--	--	--	-	-
infiltration	good air tightness + mech. exhaust	--	-	-	-	-	0	0
	medium air tightness + mech. exhaust	--	--	--	-	-	+	++

Scores in the table:
++ : 100-95% + : 95-85% 0 : 85-75% - : 75-50% -- : 50-0%
mean the percentage of the occupied zone that fulfils the comfort conditions.

Table 7 : Comfort for different ventilation supply types depending on outside temperature

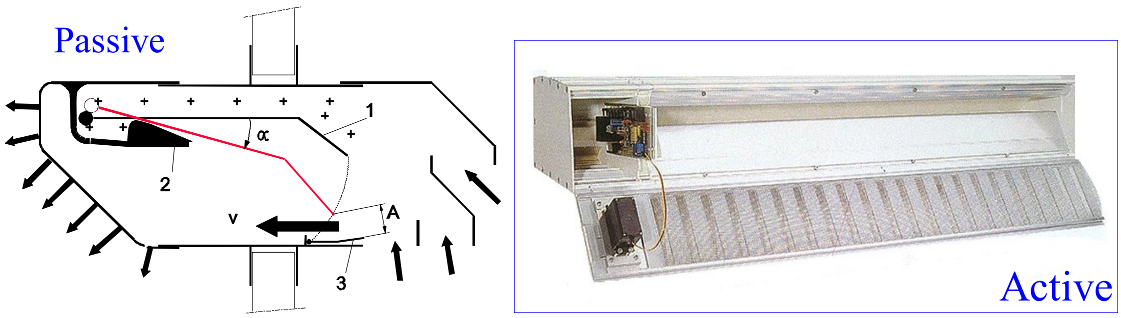


Figure 20 : Passive and active controlled air inlets

Buildings	Last date for first inspections of existing building	Inspection intervals	Inspector qualifications
Day-care centres, schools, health care centres, etc.	31 dec. 1993	2 years	K
Blocks of flats, offices, with balanced ventilation	31 dec. 1994	3 years	K
Blocks of flats, offices, with mechanical exhaust	31 dec. 1995	6 years	N
Blocks of flats, offices, with natural ventilation	31 dec. 1995	9 years	N
One- and two-family houses & balanced ventilation	31 dec. 1995	9 years	N

Table 8 : Requirements for performance checks of ventilation systems in Sweden

6.4 THE REASONS FOR (POOR AND GOOD) PERFORMANCE

6.4.1 General

This chapter presents a brief description of the possible reasons for lack of performance and good performance in ventilation systems.

Examples of possible reasons for non-quality :

- Poor design due to low fees
- Poor design due to lacking or poor specifications
- Poor workmanship
- Poor commissioning e.g. missing or poor functional checks and measurements

Use of the system other than was assumed during the design stage

- Inadequate maintenance (Liddament 1996)
- Need for maintenance ignored during design (Liddament 1996)
- Lacking or inappropriate operations and maintenance instructions

Examples of Possible reasons for good quality :
(the list could be made longer using what is written in the guidelines)

- Good design with performance oriented specifications
- Understanding the design by the people executing the system
- Active project-leader initiating the craftsmen on site
- Regular inspection during installation (construction) phase
- Good commissioning on system level not adjusting components only
- Appropriate operations and maintenance
- Regular cleaning and maintenance of good quality

6.4.2 Lack of awareness of poor performances

Many ventilation systems in buildings are performing poorly. However, poor ventilation may not always be recognised by the occupants of a room. People entering a room will detect poor odour in most cases, however after a period their sensitivity to the odour will decrease. Also, there are many pollutants which impact on IAQ that have no odour at levels which can occur in buildings.

The managers of the building systems should take measures to improve the IAQ level in buildings. Their education is often not at the right level and hence their understanding of the systems is poor.

6.4.3 Lack of enforcement of requirements

Although almost all-European countries have standards on ventilation the performance of ventilation systems in daily practice shows a lot of shortcomings. Apart from the situation in Sweden for ventilation where the OVK procedure is part of the legislation there is no other country with obligatory checks. In Sweden they have also the AMA procedure, which give specifications for the design and implementation of ventilation systems. The AMA system is applied on a voluntary basis.

6.4.4 Lack of requirements and stimuli at legislations level

In the regulations for the energy performance of buildings more and more countries specify a energy performance at the building level. Examples are the Dutch Energy Performance Standard (NEN 2916) and the Minergie rules in Switzerland. This type of rules stimulates innovative solutions.

6.4.5 Lack of clear requirements

Sometimes requirements are not quite clear. For instance a requirement that the ventilation rate for a building should be 0.5 h^{-1}. Specifying 0.5 h^{-1} without specifying under which circumstances it should be fulfilled (for instance weather or position of the ventilation system) or without specifying the distribution over the different rooms in the building is a hopeless venture.

6.4.6 Lack of specifications

The fact that customers don't require a handing over report and clear maintenance instructions for the use of the building and systems regularly leads to problems during the use of the building. Specifications should include accurate and unambiguous test methods that are available. Qualified personnel are required to overcome a lot of problems which are now in most cases unavoidable.

6.5 GOOD EXAMPLES

Good examples are not easy to be found in real practice. They exist but in most cases because of special reasons (de Gids, 2001) [Ref 10]. A good example of flow rates in an office building is given in Figure 21. (B&H building Esslingen CH) The main reason for success, is the fact that the engineers planned a building for themselves. The professional maintenance and controlling of the system is also guaranteed. There are no noise and draught problems reported. All flow rates are within the range of ± 20% of the designed flow rates

Another example although not perfect is a dwelling in the Netherlands, with a mechanical exhaust (apartment Den Haag 2000) (Figure 22) In this apartment building the inhabitants have there own individual exhaust system, which can be controlled by the occupant. In this case the occupant can always find a fan position to reach the required flow rates according to the regulations. In some control positions the occupant can even improve that situation, while there is also a power save position. The fan power for this system is about 30 W, the sound pressure level is lower than 30 dB(A) at maximum fan speed.

The reason for this successful exhaust system was a good design and execution.

Figure 21 : Esslingen office Basler & Hofmann

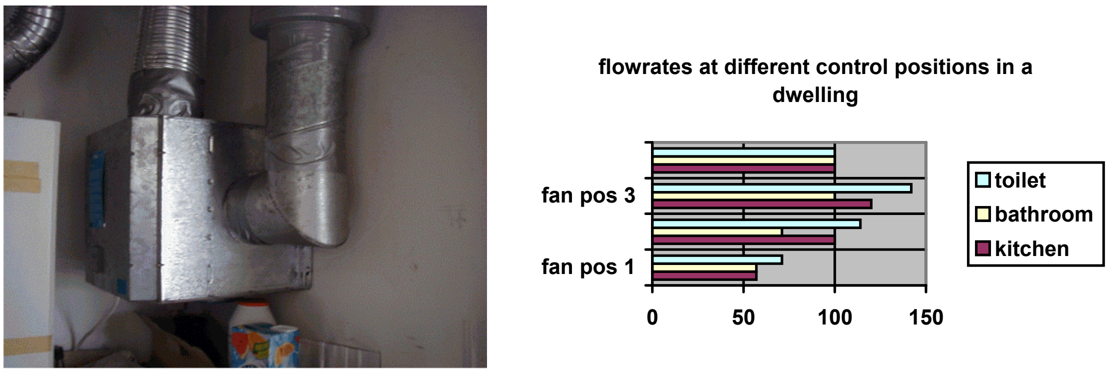


Figure 22 : Results of an apartment exhaust system in the Hague NL

7 CONCEPTS FOR ACHIEVING IMPROVED VENTILATION SYSTEMS

7.1 PERFORMANCE OBJECTIVES

This section outlines the main criteria that affect the performance of mechanical ventilation systems. Criteria are both performance-oriented and functional /descriptive in nature. Although differing in their approach, both types of criteria can be combined in an overall performance specification framework (Pennycook, 2000) [Ref 24].

A wide range of criteria influences the performance of a ventilation system, both design related and process related.

7.1.1 Design related performance-oriented criteria

7.1.1.1 Air quality

Although the provision of appropriate indoor air quality is the main objective of a ventilation system it is difficult to quantify performance-oriented approaches in a specification framework. The only practical way of quantifying indoor air quality is by means of metabolic CO_2 levels (this approach infers the level of air quality). This approach however has serious limitations as it ignores any ventilation requirement to dilute other pollutants such as volatile organic compounds (VOCs), tobacco smoke, particulates and radon etc . While VOCs can be measured in buildings the cost of doing so is too high for most practical applications. Particulates can however be measured at a reasonable cost and can therefore be included in a specification framework.

It is important that emissions from building fabric and contents are minimised.

7.1.1.2 Ventilation rate

In practice indoor air quality is usually specified indirectly through the specification of ventilation rates as in CR 1752 [Ref 33] and prEN13779 [Ref 32]. With this approach ventilation rates can be specified in terms of l/s/m² or l/s/person.

7.1.1.3 Operative temperature

The primary aim of most mechanical ventilation systems is the supply of adequate levels of outside air to occupied zones. However, ventilation systems may also be used to control summertime internal temperatures without the use of mechanical cooling. For this type of system (along with hybrid cooling systems) it is important that the required internal air temperature is specified.
CR 1752 includes performance-orientated criteria of Operative Temperature for different seasons (summer and winter) and categories of buildings. An enhanced performance-orientated approach is the specification of x degrees variation from the operative temperature for y hours per year.

7.1.1.4 Draught

Draught is normally quantified by the use of a Draught Rating that provides an estimate of the percentage of people likely to be dissatisfied with a particular level of draught. This is based on a permissible mean air velocity determined from the local air temperature and turbulence intensity. A Draught Rating can be viewed as a performance-oriented approach, however verification in the field requires the use of expensive air velocity measuring equipment that tends to be very fragile.

7.1.1.5 Thermal comfort

The concept of thermal comfort combines the influence of air temperature, mean radiant temperature, air movement and humidity with occupant clothing and activity levels to provide a quantification of occupants' likely satisfaction with their thermal environment. The performance-orientated indices of predicted mean vote (PMV) and predicted percentage dissatisfied (PPD) can be used to partly specify the performance of a mechanical ventilation system when it is intended to provide cooling in addition to the supply of outside air.

As with draught the cost of suitable equipment for on-site measurement can prove to be both prohibitively expensive and fragile.

7.1.1.6 Energy performance

Energy performance targets can be applied at the building, system and component levels.

Energy targets at Building level
This is the 'highest' level of energy performance target.

Advantages:

- Allows maximum design flexibility providing the overall energy target is not exceeded.
- Stringent targets will result in adoption of innovative mechanical ventilation solutions and good levels of component/system management.
- May limit the requirement/scope for other performance criteria. Main exceptions are those relating to health/comfort and running/operating costs (maintenance requirements etc).

Disadvantages:

- A suitable regulatory regime would have to be set up, potentially at the design or completion stage of the building and possibly during its life.

Energy targets at system level
System energy targets can be applied at the level of a complete mechanical ventilation system (eg kWh/m^2 of treated area).

Advantages:

- Allows flexibility in design, ie the designer can specify a solution to meet a particular requirement without any limitation providing the overall target is met. Energy inefficient products could be specified (they may have other beneficial attributes) providing that the energy 'loss' was balanced by more efficient components that allowed the overall energy target to be met.
- Will encourage innovative solutions/components if the system target was sufficiently stringent.

Disadvantages:

- Difficulty associated with how to prove to a regulatory authority that the entire system meets the overall energy target. Computer simulation is too expensive and not sufficiently accurate. Monitoring of energy consumption, when the ventilation system is operational, could prove to be problematic as 'spot' measurements may not be representative due to factors including seasonal influences and part-load influences (eg variable speed/DCV techniques). (Note that the monitoring of constant volume systems is relatively simple.) Monitoring by the use of electricity meters will require the relevant components of the ventilation system to be solely connected to one or more meters.

Energy targets at component level
Energy targets can be applied at the component level.

Advantages:

- Encourage innovation/improved efficiency at the component level if the energy target is sufficiently stringent.
- Designer can estimate the system energy consumption based on energy consumption data of the individual components. This will require manufacturers to publish accurate component efficiency data.

Disadvantages:

- Little scope for selecting relatively energy inefficient components, balanced by other system components with high efficiencies. (Will require the adoption of the System Target approach.)
- Efficiency of one component may impinge on the efficiency of another.
- Difficulties associated with verifying actual on-site energy efficiency (same as those identified under the System Target approach).

7.1.1.7 Acoustic performance

Noise Rating (NR) curves are used in some European countries. Similar alternatives are Noise Criteria (NC) curves. NR/NC curves consist of a family of octave band spectra covering the frequency range 63 Hz to 8KHz. CR 1752 provides permissible noise levels in terms of dB(A). Such an approach gives no information relating to the frequency content of the sound.

An advancement on the NR/NC approach is the use of Room Criterion (RC) curves. In practice, RC curves are more stringent at lower frequencies than NR/NC curves.

7.1.1.8 Ductwork air tightness

Ductwork airtightness can be specified in terms of l/s per m^2 of duct surface area, calculated as a function of differential pressure. An alternative approach is to define the leakage as a percentage of the flow through the duct, however, the following should be taken into consideration:

- The air leakage of a duct is related to its surface area and there is no direct relationship between the volume of air conveyed and the surface area of the ductwork. It can therefore be difficult to express air leakage as a percentage of total volume.
- Ductwork manufacturers/fabricators may be reluctant to implement leakage performance requirements on the basis of percentage of flow. In practice the surface area of a duct will change throughout the building. This would require constructing the ductwork to different degrees of airtightness in order to maintain the overall air leakage performance requirement.
- A third possible approach is to limit air leakage by defining stringent energy targets for the ventilation system. This should encourage the use of tighter ducts if the energy targets are suitably stringent. In practice, however, the system designer will still have to specify ductwork airtightness to ensure that the ductwork is fabricated to an appropriate standard in order that the overall energy target of the ventilation system is met.

7.1.1.9 Control system performance

A performance-oriented approach for control system performance can include:

- attainment of desired set points
- attainment of desired set points within specified time (following say system start-up)
- stability of control loops (avoidance of hunting etc)
- minimal overshoot
- minimal off-set
- speed of communications (time taken to send and retrieve information)
- ease of use of operator interface (time taken to perform specified actions)
- ease of use of occupant user interface (ease of altering set points/switch status using interface devices).

7.1.2 Process related criteria

7.1.2.1 Commissioning

A performance-oriented approach to commissioning can focus on the attainment, by the mechanical ventilation system, of specified requirements. These requirements can be divided into the following levels:

Level 1

- attainment of adequate internal environmental conditions (IAQ, air temperature and relative humidity)
- energy consumption.

Level 2

- air flow rates (total and through branches & terminal devices)
- air flow patterns/velocities in the occupied zones.

7.1.2.2 Maintenance

Performance-orientated approaches to maintenance can relate to the concept of ARM (availability, reliability and maintainability), where maintainability is defined as the mean time to repair (mttr) which represents the total plant downtime.

Under the ARM approach, availability is defined as the proportion of time that an item of plant is in operation and can be put to use, while reliability is defined as the mean time between failures (mtbf) or sometimes failures per million hours.

Availability is given by:

$$A = MTBF/(MTBF + MTTR)$$

Maintenance is normally performed in accordance with descriptive requirements, usually a specification defining what maintenance requirements are to be performed. Maintenance strategies usually adopted include Breakdown Maintenance (BM) or Time Based Maintenance (TBM).

Another performance-oriented approach is Condition Based Maintenance (CBM). Available techniques include vibration analysis, thermal imaging and the use of building management systems (BMS) as a condition-monitoring tool. In each case performance-oriented criteria can be applied. CBM techniques are however in general only realistic in large commercial/public buildings.

The hygiene of a mechanical ventilation system can be assessed in terms of the following:

- Deposit thickness test (DTT), which determines the mean surface deposit in terms of micron thickness.

- Vacuum test (VT), which determines the mean deposit weight in grams per m^2.

7.2 IMPORTANT BOUNDARY CONDITIONS

In order to achieve mechanical ventilation systems with improved performances, it is important to clearly specify the critical performances. This was discussed in 7.1 . However, unless a number of important boundary conditions are achieved, the situation in daily practice may not change very much. Therefore, it is important to have a good understanding of important boundary conditions for achieving a real change in daily practice.

- **Awareness among the decision makers**

  A crucial boundary condition for achieving improved performances of mechanical ventilation systems (as discussed in 7.1) is increased awareness among the decision makers. At present, the requirements are too often not sufficient and/or not well expressed. Moreover, the verification of these requirements is seldom correctly done. Achieving increased awareness among the decision makers (the customers and society) is essential.

- **Requirements of the customer and of society which are unambiguous and applicable in daily practice**

  It is important that a customer and society are aware of the importance of certain performances. However, only if these requirements are unambiguously stated and applicable in daily practice, one can expect that they will be met.

  As an example, 'draught' may be identified as a critical performance. A correct definition of the draught criteria is crucial and, moreover, the procedure to be used for proving that the criteria are met should be neither too complicated nor costly.

- **Requirements which are performance based with respect to indoor climate and energy efficiency**
  In cases were sufficient attention is paid to good indoor climate conditions and energy efficiency, there is an increased probability that the suppliers will deliver good ventilation systems. If these requirements are performance based, the use of innovative systems will probably be stimulated.

- **Efficient and effective quality assurance procedures**
  In most market conditions, there is a large risk of poor performance in relation to indoor climate and energy efficiency if the suppliers are aware that there is little attention for quality assurance by the customers and by society. Therefore, it is very important to have efficient and effective quality control. Appropriate handing over procedures are crucial for obtaining good indoor climate conditions and the requested energy efficiency level.

Besides the more technical boundary conditions, there are also various non-technical boundary conditions. Among others, the following are important :

- **Clear agreement between the customer and the design team concerning the requirements**
  In many countries and projects, there is not from the beginning of the project a clear set of requirements (programme of requirements or the brief) concerning the expectations of the customers. In the case of ventilation systems, it may concern requirements in relation to air quality, emission of building materials, thermal comfort, acoustical performances, energy efficiency measures,…). If such requirements are agreed and verified at the end of the project, there is an increased probability of achieving good designs.

- **Payments schemes which motivate designs of energy efficient ventilation systems with good indoor climate**

  In cases where consultants are paid on the basis of a percentage of the installation cost, there probably is in many cases little motivation for paying a lot of attention to energy efficiency and indoor climate. Alternative approaches (e.g. fixed fee in combination with a clear brief) can better stimulate good designs

- **Boundary conditions for building promoters which stimulate investments in energy efficient ventilation systems with good indoor climate performances**
  The importance of building promoters is increasing. Given the fact that they are not making use of the building, they have no

direct advantage in good indoor climate conditions and a low energy use. Therefore, it is important that they have boundary conditions which motivate them to pay attention to good indoor climate and energy efficiency measures. Such boundary conditions can be e.g. skilled clients, a proof that a whole range of requirements is met (e.g. Swedish AMA procedures), compliance with regulations (e.g. energy performance regulation).

7.3 GUIDELINES FOR DESIGN

The purpose of the guidelines (Blomsterberg, 2000) [Ref 6] is to give guidance to practitioners (primarily HVAC-designers and building managers, but also clients and building users) in how to bring about ventilation systems with good performances applying conventional and innovative technologies. The guidelines are applicable to ventilation systems in residential and commercial buildings, and during the entire life cycle of a building i.e. brief, design, construction, commissioning, operation, maintenance and deconstruction.

The following prerequisites are necessary for a performance based design of a ventilation systems:

- Performance specifications (concerning indoor air quality, thermal comfort, energy efficiency etc.) have been specified for the system to be designed.
- A life cycle perspective is applied.
- The ventilation system is considered as an integral part of the building.

The aim is to design a ventilation system, which fulfils project specific performance specifications (see chapter 7.1), applying conventional and innovative technologies. The design of the ventilation system has to be co-ordinated with the design work of the architect, the structural engineer, the electrical engineer and the designer of the heating/cooling system. This in order to ensure that the finished building with heating, cooling and ventilation system performs well. Last and not least the building manager should be consulted as to his special wishes. He will be responsible for the operation of the ventilation system for many years to come. The designer therefore has to determine certain factors (properties) for the ventilation system, in accordance with the performance specifications. These factors (properties) should be chosen in such a manner that the overall system will have the lowest life cycle cost for the specified level of quality. An economical optimisation should be carried out taking into account:

- Investment costs
- Operating costs (energy)
- Maintenance costs (change of filters, cleaning of ducts, cleaning of air terminal devices etc.)

Some of the factors (properties) cover areas where performance requirements should be introduced or made more stringent in the near future. These factors are:

- Design with a life cycle perspective
- Design for efficient use of electricity
- Design for low sound levels
- Design for use of building energy management system
- Design for operation and maintenance

7.3.1 Design with a life cycle perspective

Buildings must be made sustainable i.e. a building must during its lifetime have a small as possible impact on the environment. Responsible for this are several different categories of persons e.g. designers, building managers. Products are to be judged from a life cycle perspective, where attention must be paid to all impacts on the environment during the entire life cycle. At an early stage the designer, the buyer and the contractor can make environmentally friendly choices. A building consists of several different components with different life spans. In this context maintainability and flexibility have to be taken into account i.e. that the use of e.g. an office building can change several times during the life span of the building.

The choice of ventilation system is usually strongly influenced by the costs i.e. usually the investment costs and not the life cycle costs. This often means a ventilation system that just fulfils the requirements of the building code at the lowest investment costs. The operating cost for e.g. a fan can be 90 % of the life cycle cost. Important factors relevant to life cycle perspectives are:

- Life span.
- Environmental impact.
- Ventilation system changes.
- Cost analysis.

A straightforward method used for life cycle cost analysis is to calculate the net present value. The method combines investment, energy, maintenance and environmental cost during part of or the entire operational phase of building. The yearly cost for energy, maintenance and environment are recalculated to a cost at present, today (Nilson 2000) [Ref 36]. With this procedure different systems can be compared. The environmental impact in costs is usually very difficult to determine and is therefore often left out. The environmental impact is to some extent taken into account by including energy. Often the LCC calculations are made to optimise the energy use during the period of operation. The main part of the life cycle energy use of a building is during this period i.e. space heating/cooling, ventilation, hot water production, electricity and lighting (Adalberth 1999) [Ref 25]. Assuming the life span of a building to be 50 years, the operating period can account for 80 – 85 % of the total energy use. The remaining 15 – 20 % is for the manufacturing and transportation of the building materials and construction.

7.3.2 Design for efficient use of electricity for ventilation

The use of electricity of a ventilation system is mainly determined by the following factors:

- Pressure drops and air flow conditions in the duct system
- Fan efficiency
- Control technique for the air flow
- Adjustment

In order to increase the efficiency of the use of electricity the following measures are of interest:

- Optimise the overall layout of the ventilation system e.g. minimise the number of bends, diffusers, cross section changes, T-pieces.
- Change to a fan with higher efficiency (e.g. directly driven instead of belt driven, more efficient motor, backward curved blades instead of forward curved).
- Lower the pressure drop at the connection fan – ductwork (fan inlet and outlet).
- Lower the pressure drop in the duct system e.g. across bends, diffusers, cross section changes, T-pieces.
- Install a more efficient technique of controlling the air flow (frequency or fan blade angle control instead of voltage, damper or guide vane control).

Of importance to the overall use of electricity for ventilation is of course also the airtightness of the ductwork, the air flow rates and the operational times.

In order to show the difference between a system with very low pressure drops and a system with up to now current practise an “efficient system”, SFP (specific fan power) = 1 kW/m³/s, was compared with a “normal system”, SFP = between 5.5 – 13 kW/m³/s (see *Table 9*). A very efficient system can have a value of 0.5 (see chapter 6.3.5 🗎).

	Pressure drop, Pa	
Component	**Efficient**	**Current practise**
Supply air side		
Duct system	100	150
Sound attenuator	0	60
Heating coil	40	100
Heat exchanger	100	250
Filter	50	250
Air terminal device	30	50
Air intake	25	70
System effects	0	100
Exhaust air side		
Duct system	100	150
Sound attenuator	0	100
Heat exchanger	100	200
Filter	50	250
Air terminal devices	20	70
System effects	30	100
Sum	645	1950
Assumed total fan efficiency, %	62	15 – 35
Specific fan power, kW/m³/s	1	5.5 – 13

Table 9 : Calculated pressure drops and SFP-values for an “efficient system” and a “current system”.

7.3.3 Design for low sound levels

A starting point when designing for low sound levels is to design for low pressure levels. This way a fan running at a low rotational frequency can be chosen. Low pressure drops can be achieved by the following means:

- Low air velocity i.e. large duct dimensions
- Minimise number of components with pressure drops e.g. changes in duct orientation or size, dampers.
- Minimise pressure drop across necessary components
- Good flow conditions at air inlets and outlets

The following techniques for controlling the air flows are suitable, taking sound into account:

- Control of the rotational frequency of the motor
- Changing the angle of the fan blades of axial fans

Type and mounting of the fan is also important to the sound level.

If the thus designed ventilation system does not fulfil the sound requirements, then most likely sound attenuators have to be included into the design. Do not forget that noise can enter through the ventilation system e.g. wind noise through outdoor air vents.

7.3.4 Design for use of BMS

The building management system (BMS) of a building and the routines for following up measurements and alarms, determine the possibilities to obtain a proper operation of the heating/cooling and ventilating system. An optimum operation of the HVAC system demands that the sub-processes can be monitored separately. This is also often the only approach to discover small discrepancies in a system which by themselves do not increase the energy use enough to activate an energy use alarm (by maximum levels or follow up procedures). One example is problems with a fan motor, which does not show on the total electric energy use for the operation of a building.

This does not mean that every ventilation system should be monitored by a BMS. For all but the smallest and simplest systems BMS should be considered. For a very complex and large ventilation system a BMS is probably necessary.

The level of sophistication of a BMS has to agree with the knowledge level of the operational staff. The best approach is to compile detailed performance specifications for the BMS.

7.3.5 Design for operation and maintenance

In order to enable proper operation and maintenance appropriate operation and maintenance instructions have to be written. For these instructions to be useful certain criteria have to be fulfilled during the design of the ventilation system:

- The technical systems and their components must be accessible for maintenance, exchange etc.. Fan rooms must be sufficiently big and equipped with good lighting. The individual components (fans, dampers etc.) of the ventilation system must be easily accessible.
- The systems must be marked with information as to medium in pipes and ducts, direction of flow etc.
- Test point for important parameters must be included

The operation and maintenance instructions should be prepared during the design phase and finalised during the construction phase.

8 LESSONS LEARNED FROM THE TIP-VENT PROJECT

1. The *TIP-Vent* project has focused on a better understanding of the performances of ventilation systems in practice, the reasons for such performances and the possibilities for achieving improvements.

2. One of the major conclusions of the project is that many ventilation systems have poor performances in relation to indoor climate and/or energy efficiency. The consequences are a too high energy use and/or a poor indoor climate (air quality, noise, draught,…). It is not seldom to find poor indoor climate conditions in combination with a high energy use.

3. The impact of the air flow rate specifications on the total energy use at building level is in most cases very important.

4. The existing requirements in regulations or project specific requirements and/or the lack of requirements are a major reason for having in many cases rather poor performances.

5. In many cases, there is not an appropriate quality control after installation. The lack of quality assurance procedures is in many cases a major reason for poor performances.

6. Examples of areas where the performance of ventilation systems can and should be improved are use of electricity, sound levels, life cycle perspective, operation and maintenance.

7. Maintenance during the lifetime of a ventilation system is crucial if good indoor climate conditions and energy efficiency has to be achieved. At present, maintenance doesn't receive in most countries and/or projects sufficient attention.

8. There are high quality ventilation systems on the market that allow the achievement of both good air quality and low energy use. Moreover, there is not necessarily a major increase in investment costs and in most cases the total life cycle cost is lower.

9. The role of society is in most cases very important for creating the required boundary conditions : standards, regulations as well as appropriate guideline documents are of great importance. A number of good examples have been identified, e.g. the Swedish AMA and OVK procedures and the Energy Performance regulation as applied or under development in various EU countries.

10. Within the framework of the *TIP-Vent* project, several new innovative ventilation concepts have been developed.

11. The implementation of well performing conventional and innovative ventilation systems is encouraged and facilitated by a performance oriented approach to design, construction, commissioning, operation, maintenance and deconstruction. Clients and users have to ask for quality by specifying requirements corresponding to a desired performance.

9 INOVATIVE DEVELOPMENTS

9.1 LOW PRESSURE SYSTEMS

The energy used for transport of air by mechanical ventilation may be a fraction of the energy used for heating the air, nevertheless the goal of LeVent was to reduce the energy used for transport to at least half of the value which can be reached with good practice in dwellings. (Bulsing, 2000) [Ref 7]

An exhaust system and a balanced system were set up in the laboratory of TNO Building and Construction Research. The installation was delivered and installed by Bergschenhoek BV. The commissioning was carried out by TNO Building and Construction Research.
Before the measurements and investigations started some brainstorm sessions were held together with Bergschenhoek BV.
A summary of the ideas can be found in Figure 23 (De Gids, 1999) [Ref 8]

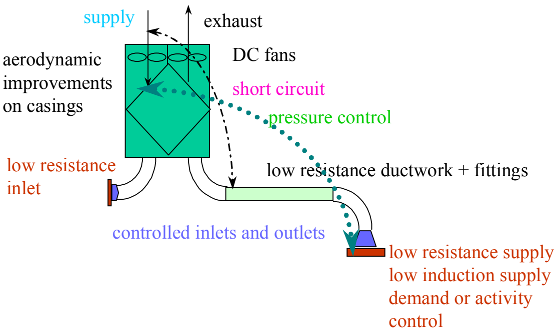


Figure 23 : Possible improvements on the system

The systems were constructed like they were really installed in a dwelling.
As reference dwelling we have used a single family dwelling.
This dwelling had a floor area of about 100 m^2.
It was one of reference dwellings for the Energy Performance Standard in the Netherlands.
The dwelling has a warm water central heating system.

In this study we consider two types of ventilation systems:

- Natural supply with mechanical exhaust (exhaust only system)
- Mechanical supply and exhaust (balanced system)

Each domestic ventilation system consists of:

- Roof outlet
- Fan(s)
- Ductwork
- Air Terminal Devices

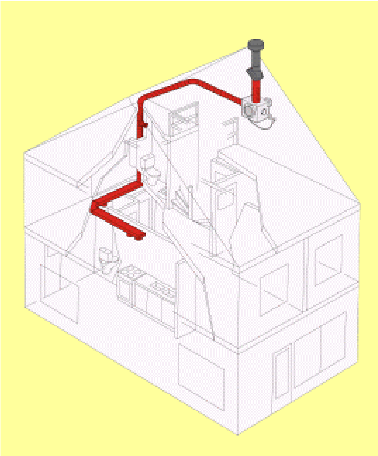


Figure 24 : Mechanical exhaust

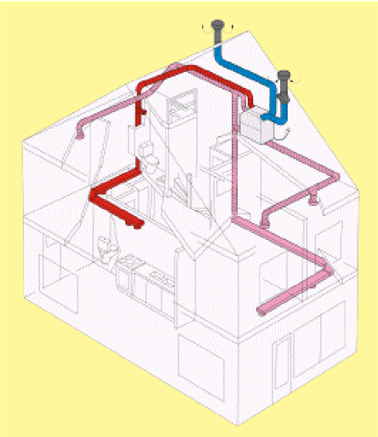


Figure 25 : Balanced ventilation system)

The system shown in Figure 34 is a ventilation system with natural supply in the façade and mechanical exhaust. The system shown in Figure 25 is a so called balanced system, where air supply to all habitable rooms is mechanically supplied, while the air is exhausted via the toilet, bathroom and kitchen. The heat of exhausted air is used to preheat the supply air. For this purpose a heat exchanger is used.

In the pictures below one may see for the two systems the ductwork and the fan units.

Figure 26 : Set-up of systems at TNO

Figure 27 : Exhaust fan (standard unit)

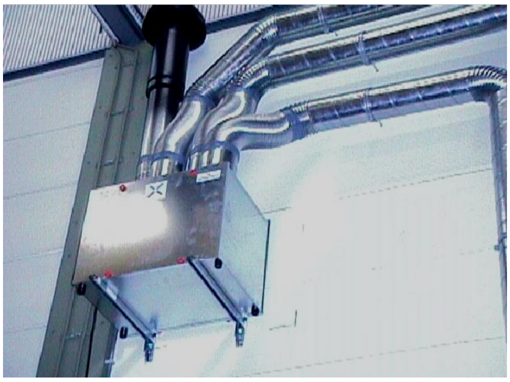


Figure 28 : Balanced ventilation unit with heat recovery

The airflow rates of the system have target values as described below:

• Kitchen	21 dm³/s
• Toilet	7 dm³/s
• Bathroom	14 dm³/s
• Total airflow	42 dm³/s

These values were adjusted through commissioning the system.

The pressure difference across the fan was about 50 Pa. The measured power by the fan was 21 Watt.

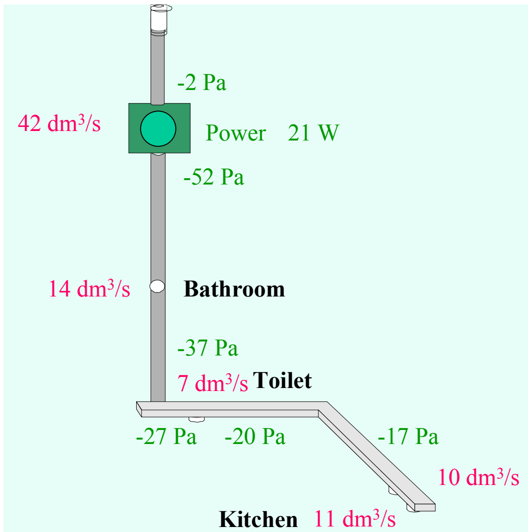


Figure 29 : Scheme of the exhaust system

Analyses of the measured data showed that:

- Fan power can be minimized by improvements such as DC fans.
- The largest resistances in the ductwork were the rectangular ducting in the ground floor
- The pressure drop at the air terminal devices are at minimum 17 Pa.

In domestic ventilation systems the ducts in the Netherlands are often installed in the concrete floors. Because of the available floor height, the use of rectangular ducts with the dimensions of 70 x 170 mm (equivalent 125 mm) is most common.

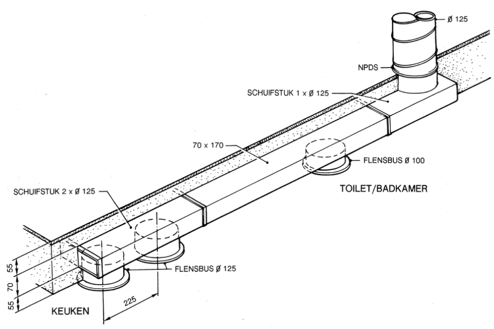


Figure 30 : Scheme of the rectangular duct system

From a study with the Multi zone model COMIS could be found that by replacing the rectangular ducting with three parallel round ducting, the pressure loss of the system could be about 50 % lower.

To optimise the aerodynamic features a new design for ducts and fittings in concrete floors is developed. The pressure drop across the ductwork was decreased by about 45%.

Figure 31 : New system for ducts in concrete

During the project the fan casing is improved strongly. Using plastics housing have internally aerodynamic shapes that minimize the pressure losses of the fan casing.

Figure 32 : Improved fan design

Apart from the aerodynamic improvements the control of the fan was also improved. A DC fan was used resulting in a better control and lower fan power.

The results of the improvements on ductwork and fan resulted in a fan power of about 7 W instead of 21 W in the reference case for a flow rate through the fan of 42 dm^3/s. The pressure drop over the fan unit decreased from about 50 to about 30 Pa.

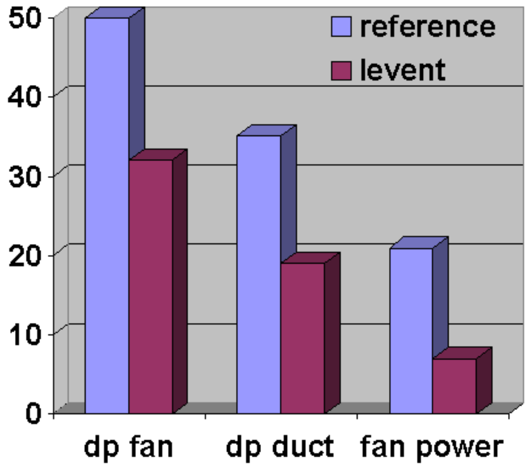


Figure 33 : Result of improvement for the exhaust system

Improvements to minimize the pressure drop over the air terminal devices resulted in the development of a constant flow controller. At about 5 Pa the flow rate should be independent of the pressure difference across the air terminal device.

9.2 ACTIVE NOISE INSULATION

In a dwelling, the noise from air ductwork : mechanical ventilation, central air conditioning systems,…can lead to discomfort.

Part of this noise comes from fans, and is transmitted through ventilation ducts.

This noise category includes low frequencies (< 500 Hz) which are very bad for human hearing and nervous systems (noise from fan blades, for example).

Classical insulation techniques are not able to treat this range of noise problems. Classical passive sound attenuators are efficient at high frequencies, but less efficient at low frequencies. This is the background for the development of an Active Noise Attenuation system (ANA).

A.N.A. is in fact the combination of a passive part (for high frequencies attenuation) and an active part (for low frequencies attenuation).

Active noise control principle is an old principle (idea from M. LUEG in 1936), and different systems have already been developed. Active noise control is based on the principle of a counter-noise, which is a sound wave with the same amplitude, same frequency, but in phase opposition with the primary wave to be attenuated. Basically, there is the need of two microphones (one measures the noise to be attenuated, and the other measures the result of attenuation), an electronic calculator (for counter noise calculation) and a loudspeaker (for counter noise emission).

ALDES and an Electronic Company, TECHNOFIRST, developed the ACTA product : active noise attenuation for medium size installations, duct diameters between 250mm and 630mm (Barles et al, 2000) [Ref 1]. The ACTA is a component of about 1.5 m length.

For smaller installations (individual dwellings, apartments, small commercial buildings,…), no system was available at the start of this project.

Small-scale applications need small components (to be incorporated inside ducts diameters from 125mm to 250mm) and, also, a reasonable cost level, These considerations were important boundary conditions for the developments within the *TIP-Vent* project. (Barles et al, 2000) [Ref 3]

But, when speaking of active noise attenuation, a small size is immediately a critical question because of the size and position of the elementary components of the system.
Also, attention should be paid to connection, operation and maintenance of A.N.A., because of the specific needs of the market; often no ventilation specialists (or installers) in small applications.

The figure, below, shows the ACTA product for “big” installations:

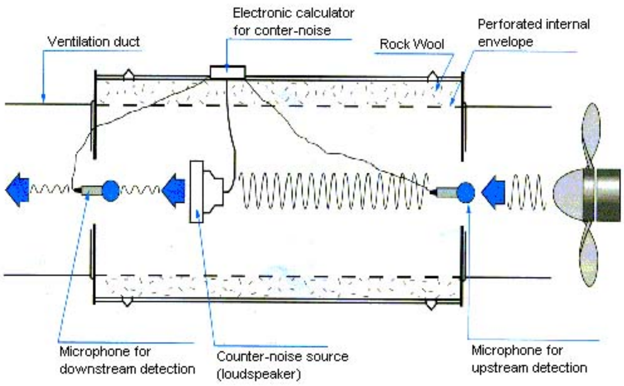


Figure 34: Existing ACTA product for “big” installations

When developing A.N.A. for small applications, starting from the existing principle and the “big” product, two main problems to solve are:

- find a compromise between loudspeaker size and its low frequency cutting ;
- find a compromise between size and efficiency of the microphone protection against turbulence.

The above scheme can’t be kept and the electronic part (using the so called LMS algorithm) has also to be adapted to the new product.

Through the development of an A.N.A. prototype, solutions were found:

- positioning of the loudspeaker and microphones on the side of the duct (instead of inside the duct) ;
- size layout of the loudspeaker : enclosure volume of 0.7 l, diaphragm diameter of 10 cm, engine diameter of 6 cm ;
- size of microphones and protections : microphone is 1 cm high, with a diameter of 1.5 cm.

Figure 38 shows the A.N.A. prototype, positioned just downstream of a small residential fan.

The following figure gives the attenuation of the active part of A.N.A. prototype, which is in development in the frame of the *TIP-Vent* Project.

As we can see, an attenuation of 10 to 15 dB is obtained between 100 Hz and 600 Hz, with some fluctuations.

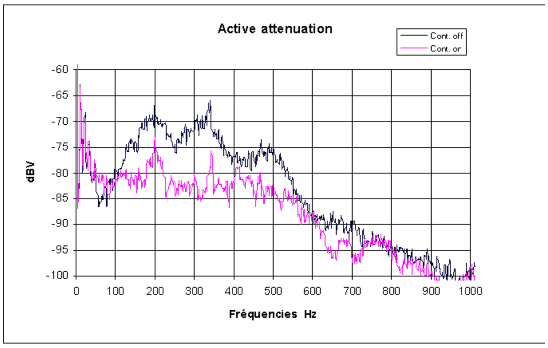


Figure 35 : Attenuation of the active part of A.N.A. prototype

Figure 36 : : Dwelling application : before ANA prototype installation

The above ANA prototype was tested on two applications:

- one individual house (120m²) equipped with a central balanced ventilation system,
- one office zone (four offices of about 20 m² each) in a commercial building equipped with a central exhaust ventilation system (measurements were made in one office).

For both applications, measurements have been made, with and without ANA, at two locations:

- inside the duct (between ANA and the room),
- inside the room.

Figure 36 and Figure 37 show the implementation of ANA prototype on the existing ventilation duct.

Figure 37 : : Dwelling application after ANA prototype installation

Figure 39 shows the attenuation inside the bedroom (fan is running at high speed). For comfort evaluation, it is important to measure the attenuation in dB(A). We also can see that the attenuation at 100 Hz, were an emerging noise from fan appears, is important (fan is running at high speed).

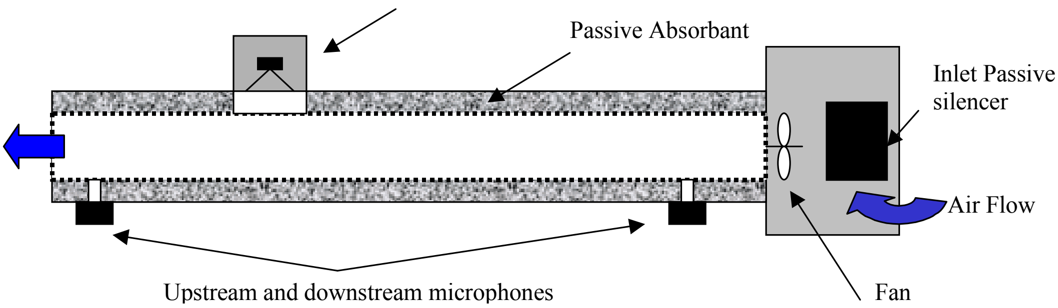


Figure 38: A.N.A. prototype

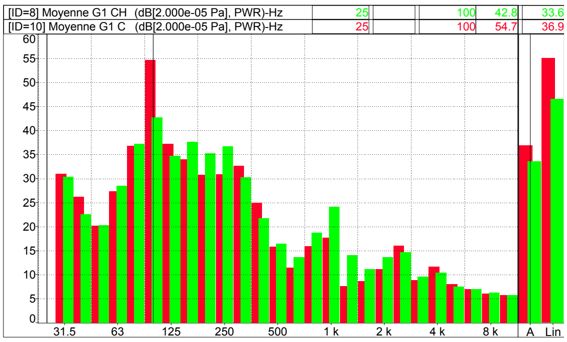


Figure 39: Active noise attenuation inside the bedroom

In <u>*RED*</u>*, is the acoustic pressure level when ANA is* <u>*OFF*</u>*.*
In <u>*GREEN*</u>*, is the acoustic pressure level when ANA is* <u>*ON*</u>*.*

The global attenuation of the noise inside the bedroom is : <u>3.5 dB(A)</u>
At 100Hz, the attenuation is : <u>12 dB(A)</u>

Figure 40 shows the ANA installation in the office case.

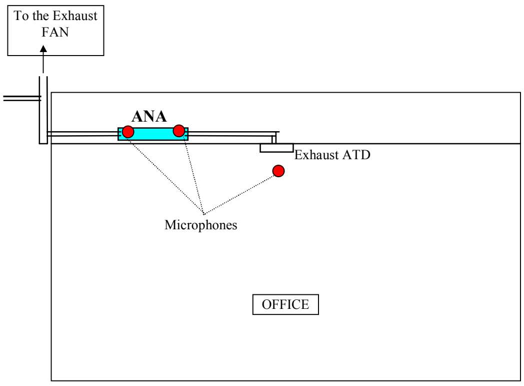


Figure 40: ANA installation in the office case

Figure 41 shows the attenuation inside the office, close to the exhaust air terminal device (background noise level was two high at the centre of the room).

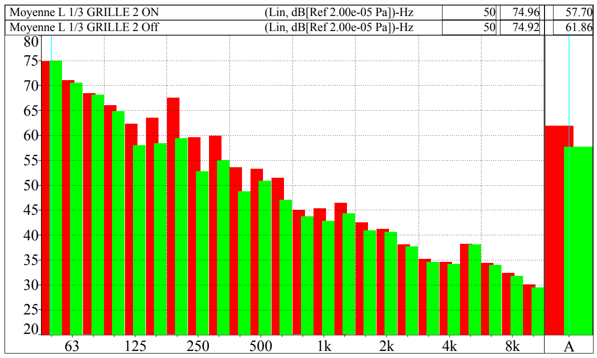


Figure 41 : Active noise attenuation inside the office (close to the exhaust ATD)

In <u>*RED*</u>*, is the acoustic pressure level when ANA is* <u>*OFF*</u>*.*
In <u>*GREEN*</u>*, is the acoustic pressure level when ANA is* <u>*ON*</u>*.*

The global attenuation, due to the active system is about <u>4.2 dB(A)</u>.

The field testing allowed the identification of some limits relating to the ANA efficiency :
the noise level upstream the ANA is an important parameter : the higher it is, the better is the attenuation ;
the attenuation will depend on the structure of the noise spectrum : attenuation will be important if a frequency is emergent ;
the performances are linked to the turbulence : air velocity inside the duct shouldn't be too high ;
the environment of ANA is influencing the performance : if the background noise is important, then the performance will be lower ;
a careful installation is necessary.

9.3 BOOST INTAKE VALVE

The ventilation needs in dwellings can be separated into two distinct types:

- the needs for "fresh air" for the occupants in the habitable or main rooms : living-room, bedrooms;
- the need for punctual extraction in non-habitable rooms where specific pollution occurs : kitchen, bathroom, toilets.

It is recognised that the first type of needs requires a quite continuous and relatively low air flow, which is sometimes called a basic air flow. The second type generally requires high intermittent and high air flow, localised in specific rooms, even often in specific places in these rooms.
It is also generally recognised (mainly for energy conservation reasons) that the air should go from the habitable rooms (where the air is supplied) to the non-habitable rooms (where the air is exhausted).

This is mainly true for the basic air flow. But for the high intermittent air flows, it is better to supply the air as close as possible to the exhaust, in the room where this air is needed; it is then not necessary to keep the same air flow pattern as before. Moreover an unnecessarily large ventilation rate supplied to the habitable rooms may result in the risk of draft or noise problems.

Based on the previous considerations, the « Boost Intake Valve » B.I.V. is an additional air inlet that allows the separation of general/permanent ventilation and intermittent high ventilation that is required for cooker hoods and drying machines etc. (Barles et al, 2000) [Ref 2]

In this way, air inlets installed in these rooms and dimensioned for this need will fulfill the need for fresh air in the habitable rooms.

The complementary ventilation needed for the intermittent high ventilation action is fulfilled by the B.I.V., positioned in the non-habitable rooms (the kitchen is the first application).

The basic requirements are: first, not to perturb the basic air flow and air flow pattern; second, to allow the high intermittent air flow. Logically, the B.I.V. shall react to increasing internal pressure. (Barles et al, 2000) [Ref 4]

Simulations on air flows in a typical dwelling show that:

- B.I.V. allows both incoming and exhaust air flows to fulfil the requirements;
- B.I.V. avoids reverse flows which could appear in other non-habitable rooms when boosted air flow is supplied to the kitchen;
- B.I.V. avoids under-pressure in the dwelling;
- B.I.V. preserves the general air flow pattern in the dwelling, and avoids the increasing of the infiltration's.

In principle, B.I.V. will be in communication with the outside of the dwelling; it will open to allow ventilation or close according to the variations of both exhausted air flow and under-pressure in the dwelling, as shown in the following figure.

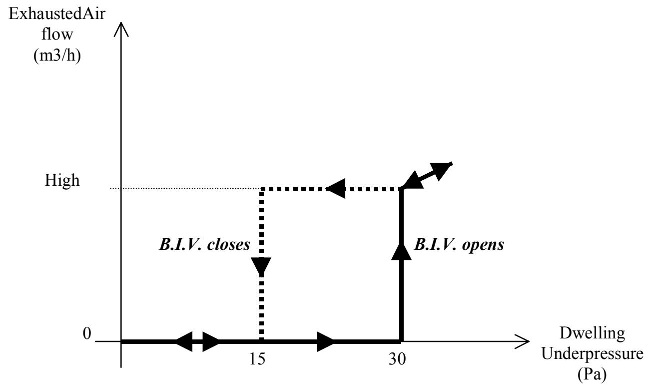


Figure 42: BIV opening/closing principle, according to the increasing/decreasing underpressure inside the dwelling

The B.I.V. prototype that was developed in the *TIP-Vent* project showed good agreement with the above aerodynamic characteristics (see figure below). It was also characterised according to the duration of the opening and closing periods (both varied between 15 s and 30 s) ; also the acoustic characteristic of sound insulation was tested in laboratory (B.I.V opened, B.I.V. closed).

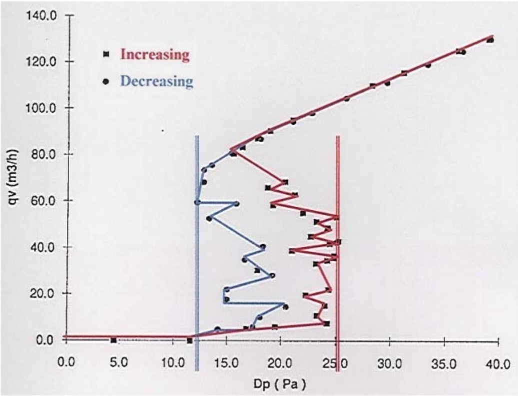


Figure 43: Laboratory measurements of BIV opening/closing according to the under pressure

Real tests of the BIV were made as part of the *TIP-Vent* project.

49 BIVs have been manufactured for these tests.

49 apartments in three different buildings (one is a new building, others are existing) have been equipped with B.I.V. along with a general mechanical ventilation system.

The example below is an existing multifamily building (location : Lyon, F-69000) :

- 10 dwellings (all the same type T3) are equipped with BIV, installed in kitchens in a high position on a north-west oriented facade
- ventilation is a central extraction system
- individual boilers are "closed" ones (separated inlet-outlet)
- windows are high quality (thermal insulation and airtightness)
- self regulated inlets and outlets

Figure 44: Multifamily building where BIV was tested

Three series of tests were defined :

- dwelling's air tightness measurements :
  - measurements of air flow / under pressure values for a wide range of air flows
- "forced" tests :
  - cycles of min/max ventilation air flows
  - characterisation of BIV behaviour (small electrical contact on the opening/closing flap)
  - measurement of the underpressure in the dwelling
- "real" tests :
  - same BIV characterisation and measurements as in "forced" tests
  - real conditions for ventilation air flows (min/max) and windows opening

The table and Figure 45 below show the airtigthness measurements results on this building.

Existing multifamily building (location : Lyon, F-69000)				
	Air inlets "self regulating"		Air inlets "closed up"	
Appt n° (type)	Under pressure (high air flow)	Permeability (1)	Permeability (2)	n50 (approx.)
	Pa	m3/h at 10 Pa	m3/h at 10 Pa	ach at 50 Pa
113 (T3)	12.6	120	65	1.09
114 (T3)	8.4	145	90	1.51
123 (T3)	11.6	105	65	1.09
124 (T3)	22.5	78	40	0.67
133 (T3)	8.2	130	63	1.06
134 (T3)	4.6	220	135	2.27
143 (T3)	5.9	180	80	1.34
144 (T3)	6	170	85	1.43
153 (T3)	8	145	70	1.18
154 (T3)	3.7	185	85	1.43

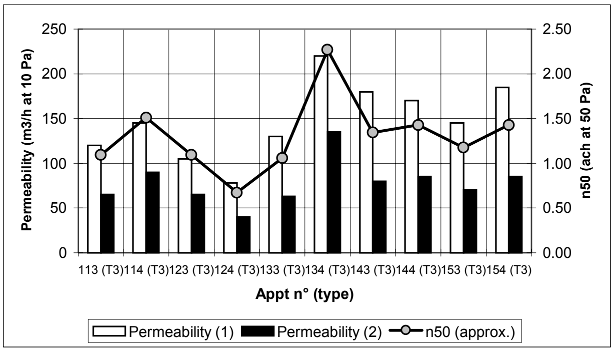


Figure 45: Airtightness measurements – Lyon building

On this building, airtightness is quite homogeneous between the different dwellings, and rather "good" : 1 ≤ n50 ≤ 1.5.

Figure 46 below shows an example of the forced test result.

On the bottom of the figure is indicated the state of the ventilation air flow (low/high), which changes every 10mn.
On the top of the figure is indicated the state of the BIV (opened/closed).

In the middle of the figure is indicated the underpressure inside the dwelling, which varies, in the present example, between 7 and 35 Pa.

In the general case, the behaviour of the BIV is correct:

- opening at about 30 Pa ;
- stabilisation around 20 Pa when the BIV is fully opened.

Sometimes the BIV is partially opened. In this case the free area of the BIV is lower and the under pressure inside the dwelling is stabilised around 25 Pa.

During the real tests, the ventilation air flows were dependent on actions of occupants on the exhaust air terminal devices (low/high) and actions on windows and doors opening.

As the under pressure inside the dwelling rarely reaches the opening pressure threshold of the BIV (even after an improvement in the airtightness: cracks, doors and windows, …), it was then decided to close up some air inlets.

In the example below (see Figure 47), all the inlets were closed:

- in this case the BIV opens when inside under pressure is between 27 and 30 Pa ;
- in some situations, between 14mn and 24mn, there is a pumping phenomena; the BIV is partially opened ; the under pressure is stabilised at different values between 17 to 23 Pa ;
- around 24.5mn, a window is opened, then the under pressure inside the dwelling is zero ;
- when BIV is fully opened, the under pressure inside the dwelling is stabilised around 15-16 Pa.

After BIV field testing, the main conclusions are:

- the global BIV behaviour is satisfactory : reaction to increasing underpressure inside the dwelling (around 30 Pa) ; underpressure inside the dwelling when BIV is opened (around 15 Pa) ; no sensitivity to wind ;
- internal frictions have to be reduced : they induce delay in closing/opening of the BIV ;
- some dysfunctions may occur in very particular situations.

Field testing showed that two main points had to be improved on the BIV product:

- the rigidity of the box,
- the rotation of the flap axle,

in order to insure a correct (in relation with the performance characteristics which were defined and measured) and reproducible behaviour of the BIV.

The next generation of BIV, ready to be put on the market, is now characterised by a better rigidity (the material constituting the box is more rigid) and by the use of two springs (return springs) instead of one (see prototype).

Other applications are conceivable in the dwelling:

- clothes dryers, which are generally placed in the kitchen, the bathroom or another wet room ;
- gas heater which can be placed in a non-habitable room, for example near the kitchen ;

Other applications are also conceivable in commercial buildings, for examples:

- laboratories in schools ;
- photocopy rooms in office buildings.

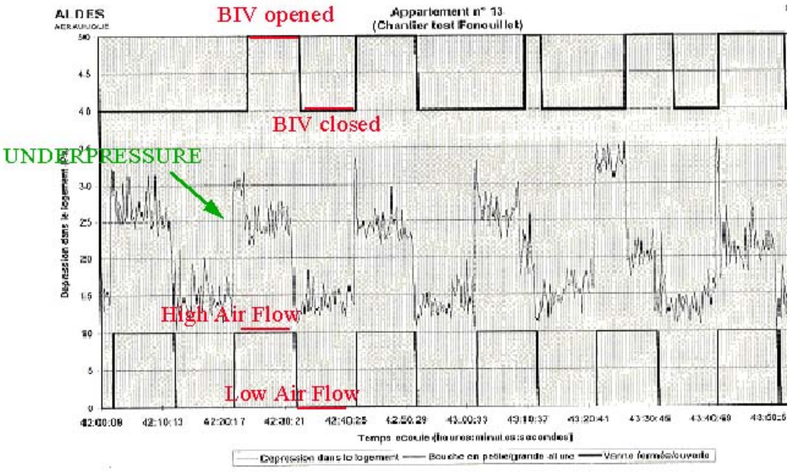


Figure 46: Example of "forced" test of BIV opening/closing

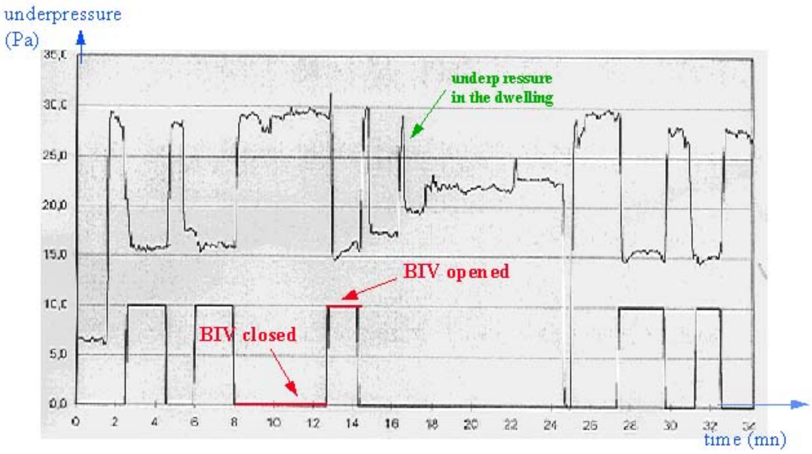


Figure 47: Example of real test of BIV

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