OPTIMUM VENTILATION AND AIR FLOW CONTROL IN BUILDINGS

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IEA ANNEX 27: Evaluation and Demonstration of Domestic Ventilation Systems. Assessments on noise.

Peter Op 't Veld, Catherine Passlack-Zwaans

Cauberg-Huygen Consulting Engineers,
PO box 480, 6200 AL Maastricht, the Netherlands

Synopsis

The acceptance and appreciation of ventilation systems is mainly determined by the perceived indoor air quality, thermal comfort and noise. Noise in relation to ventilation systems can be divided into three categories:

- outdoor noise (entering the dwelling through ventilation openings, cracks, mechanical supply and exhaust openings etc.);
- noise generated by components of the ventilation system;
- the impact of ventilation systems on sound reduction of partitions (between dwellings, rooms etc.).

Depending on the type of ventilation system, one or more of these aspects are of concern. Noise related to the ventilation system and components, can result in turning off the ventilation system or closing vents etc. This can have a negative influence on ventilation and indoor air quality. In the framework of IEA ANNEX 27 several noise aspects of domestic ventilation systems have been evaluated.

Outdoor noise:
In noise loaded areas the selection and the applicability of different types of ventilation systems are determined by the noise level on the facades. A simplified tool is developed to select ventilation systems as a function of the required noise reduction of the facade, room dimensions and design and construction of the facade.

System noise:
Controlling noise levels caused by ventilation systems is in practice one of the most important factors to contribute to the satisfaction with a ventilation system. Air duct systems in dwellings transport noise generated by fans and aerodynamic noise generated by bends, control valves, grilles etc. ANNEX 27 gives basic formulas to estimate sound power levels of fans and grilles, indication of sizes for silencers and guidelines for design.

Impact on noise reduction of partitions:
The composite sound reduction is the result of different sound channels from one room to the other. One of this sound channels may be the ventilation system (cross-talk). Cross-talk can be brought about through the air duct system, overflow grilles and ventilation openings in partitions, duct transitions etc. ANNEX 27 provides guidelines for sound reductions of partitions and insertion losses for ducts to eliminate the influence of cross-talk.

1. Introduction

Satisfaction with a ventilation system is largely determined by the perceived indoor air quality, thermal comfort (i.e. draft control) and noise aspects. In practice, controlling noise aspects, in particular reducing noise levels, is one of the most important factors that contribute to the satisfaction with a ventilation system. Noise aspects related to ventilation systems can be divided into direct noise and indirect noise. Direct noise is noise generated by the system itself. The system is both the source and the means of transport for noise. Examples are noise generated by fans and by mounting materials of air ducts (structure born noise), and noise generated by control valves and grilles (aerodynamic noise).

Indirect noise includes all noise of which the source is outside the system. In this case the system merely transfers noise which originates outside the system. Examples are traffic noise, noise from industrial plants, catering establishments and aircraft (outdoor noise), and domestic noise (internal noise sources). In general, the following three ventilation principles apply to dwellings:

- natural air supply and natural air exhaust;
- natural air supply and mechanical air exhaust (local and/or central systems);
- mechanical air supply and mechanical air exhaust (balanced ventilation), with or without heat recovery.

Noise related to domestic ventilation systems can be divided into three main areas:

- outdoor noise entering the dwelling through ventilation openings (cracks, grilles, and air supply- and exhaust openings);
- noise generated by the ventilation system of the rooms of the dwelling;
- sound transported within or between dwellings by the ventilation system and/or internal ventilation provisions.

Depending on the type of ventilation system and the strategy, one or more of the three areas indicated in table 1 below are important.

Table 1: Noise importance

	Natural ventilation	**Mechanical exhaust**	**Balanced ventilation**
Outdoor noise	x	o	o
System noise	-	x	x
Sound transmission	o	o	x

- irrelevant/not applicable
o in general of minor importance
x important

2. Outdoor noise

Requirements and methods of calculation and measurement

Road traffic and other activities like industrial plants can cause a noisy environment. In general, the allowable sound level in rooms is 35 dB(A) (ISO 1996). However, in some countries only 30 dB(A) is allowed (Sweden, Finland). The noise reduction of a facade (G_A) is the difference between the outdoor noise level and the perceived indoor noise level:

$$G_A = L_o - L_i \qquad [\text{dB(A)}]$$

Where:
G_A is the noise reduction of a facade
L_o is the outdoor noise level
L_i is the indoor noise level.

The resulting sound reduction is determined by the overall sound reduction of the facade (R_A), taking also into account the noise transfer through ventilation openings and joints and cracks in the construction, and the (acoustic) properties of the room itself:

$$G_A = R_A + 10 \log A/S - 3 \qquad [dB(A)]$$

Where:

R_A	is the overall sound reduction of the facade in dB(A)
A	is the room absorption of the room in m^2 sabine
S	is the total surface area of the facade in m^2
-3	is the correction for direct sound field to diffuse sound field

Ventilation and infiltration through the building envelope is taken into account in the overall sound reduction R_A. This includes:

- joints and cracks around windows and doors (uncontrolled ventilation);
- ventilation openings in the facades (grilles and windows ajar);
- air ducts in facades and the roof, with or without grilles.

Noise reduction of facades

In noise loaded areas the selection and the applicability of different types of ventilation systems is determined by the noise level on the facade. Dwellings with facades containing windows with single glazing or standard double glazing without weather-stripping achieve a noise reduction of approximately 20 dB(A). With the windows in the ventilation position (ajar), a noise reduction of approximately 15 dB(A) can be achieved. If outdoor noise levels at the facade exceed 50 to 55 dB(A), natural supply systems will require special acoustic measures, particularly with regard to the ventilation system. The transfer of noise through facades takes the following paths:

- closed facade areas (brickwork, panels);
- glass;
- ventilation openings;
- joints and cracks.

Simplified tool

As to determine the most efficient ventilation system in a noisy environment a number of choice matrices are developed, presenting the applicability of ventilation systems with respect to the required noise reduction level, the percentage minor soundproofed parts of the facade and the dimension of the ventilation openings. These matrices are a simplified tool to select the most appropriate ventilation system for a room, if the required noise reduction of the facade, the dimension of the ventilation opening, and the percentage of minor soundproofed parts (such as glass, light weighted panels) in the facade are known. An example of the matrices is shown in figure 1.

The applicability of the ventilation systems is represented in the matrices, as follows:

-	system not applicable;
0	system applicable if combined with excellent sound proofed measures (high quality acoustic glazing, double weather-stripping);
+	system applicable if combined with normal sound proofed measures (normal acoustic glazing, good single weather-stripping);
++	system applicable without extra sound proofed measures (standard double glazing, weather-stripping).

S_{facade} = 15 - 25 m^2

Ventilation system		$G_{a;c}$ = 20 dB(A)														
		Percentage of inferior soundproofing constructions in the facades exosed to traffis noise [%]														
		0					< 50					≥ 50				
		A netto [cm^2]					A netto [cm^2]					A netto [cm^2]				
		0-50	50-100	100-200	200-400	≥ 400	0-50	50-100	100-200	200-400	≥ 400	0-50	50-100	100-200	200-400	≥ 400
Natural supply	Ventilation opening without soundproofing: R_a = -5 dB(A)	++	++	++	++	-	++	++	+	+	-	++	++	++	0	-
	Soundproofed ventilation opening: R_a = 0 dB(A)	++	++	++	++	++	++	++	++	++	+	++	++	++	++	++
	Soundproofed ventilation opening: R_a = 10 dB(A)	++	++	++	++	++	++	++	++	++	++	++	++	++	++	++
	Soundproofed ventilation opening: R_a = 15 dB(A)	++	++	++	++	++	++	++	++	++	++	++	++	++	++	++
Mechanical supply and exhaust		++	++	++	++	++	++	++	++	++	++	++	++	++	++	++

Ventilation system		$G_{a;c}$ = 25 dB(A)														
		Percentage of inferior soundproofing constructions in the facades exosed to traffis noise [%]														
		0					< 50					≥ 50				
		A netto [cm^2]					A netto [cm^2]					A netto [cm^2]				
		0-50	50-100	100-200	200-400	≥ 400	0-50	50-100	100-200	200-400	≥ 400	0-50	50-100	100-200	200-400	≥ 400
Natural supply	Ventilation opening without soundproofing: R_a = -5 dB(A)	++	++	-	-	-	++	-	-	-	-	++	0	-	-	-
	Soundproofed ventilation opening: R_a = 0 dB(A)	++	++	++	++	-	++	++	+	0/-	-	++	++	+	0	-
	Soundproofed ventilation opening: R_a = 10 dB(A)	++	++	++	++	++	++	++	++	++	++	++	++	++	++	++
	Soundproofed ventilation opening: R_a = 15 dB(A)	++	++	++	++	++	++	++	++	++	++	++	++	++	++	++
Mechanical supply and exhaust		++	++	++	++	++	++	++	++	++	++	++	++	++	++	++

Ventilation system		$G_{a;c}$ = 30 dB(A)														
		Percentage of inferior soundproofing constructions in the facades exosed to traffis noise [%]														
		0					< 50					≥ 50				
		A netto [cm^2]					A netto [cm^2]					A netto [cm^2]				
		0-50	50-100	100-200	200-400	≥ 400	0-50	50-100	100-200	200-400	≥ 400	0-50	50-100	100-200	200-400	≥ 400
Natural supply	Ventilation opening without soundproofing: R_a = -5 dB(A)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Soundproofed ventilation opening: R_a = 0 dB(A)	++	++	-	-	-	+	-	-	-	-	0	-	-	-	-
	Soundproofed ventilation opening: R_a = 10 dB(A)	++	++	++	++	++	+	+	+	+	+	+	+	+	0	-
	Soundproofed ventilation opening: R_a = 15 dB(A)	++	++	++	++	++	+	+	+	+	+	+	+	+	+	0
Mechanical supply and exhaust		++	++	++	++	++	+	+	+	+	+	+	+	+	+	+

Ventilation system		$G_{a;c}$ = 35 dB(A)														
		Percentage of inferior soundproofing constructions in the facades exosed to traffis noise [%]														
		0					< 50					≥ 50				
		A netto [cm^2]					A netto [cm^2]					A netto [cm^2]				
		0-50	50-100	100-200	200-400	≥ 400	0-50	50-100	100-200	200-400	≥ 400	0-50	50-100	100-200	200-400	≥ 400
Natural supply	Ventilation opening without soundproofing: R_a = -5 dB(A)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Soundproofed ventilation opening: R_a = 0 dB(A)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Soundproofed ventilation opening: R_a = 10 dB(A)	++	++	-	-	-	0	0	-	-	-	-	-	-	-	-
	Soundproofed ventilation opening: R_a = 15 dB(A)	++	++	++	++	++	0	0	0	0	-	0	0	-	-	-
Mechanical supply and exhaust		++	++	++	++	++	0	0	0	0	0	0	0	0	0	0

Figure 1: Choice matrices which present the applicability of ventilation systems in a noisy environment

3. Noise generated by the ventilation system

Requirements and methods of calculation

The air duct system inside dwellings is responsible for the transport of noise generated by the fan and aerodynamic noise generated by bends, control valves and devices. The maximum indoor noise level criteria in most countries, with respect to noise generated by the ventilation system in rooms, is 30 dB(A). The sound power level (L_w) at the optimal operating point of the fan can be approximated by means of the following simplified formula:

$$L_W = L_{WS} + 10 \log q_v + 20 \log \Delta p \quad [dB]$$

Where:

L_{WS} = 1 ± 4 dB
q_v is the flow capacity in m^3/h
Δp is the total pressure difference across the fans (Pa)

In general, fans for single family dwellings have a A-weighted sound power level $L_{W(A)}$ of 60 to 65 dB(A).

Sound reducing measures inside air ducts

The noise generated by fans is propagated through the air duct system. If no special noise soundproofing measures are taken, the resulting noise levels can be considerably higher than 30 dB(A). Without special soundproofing measures, internal noise levels of up to 45 dB(A) in rooms can be expected. This requires the use of soundproofing materials inside the air duct system. Soundproofing materials in the supply system should ideally be placed immediately after the unit, but always before the first branching of the duct. Soundproofing provisions for domestic ventilation systems usually consist of soundproofing (flexible) tubes (silencers). Silencers are relatively cheap and easy to integrate in an air duct system. They demand hardly any extra space. A silencer consist of a perforated inner duct, a casing of mineral wool and an outer duct. The ducts may be plastic or metal and are often flexible to a certain extent. The noise attenuation of these materials is poor at low frequencies. Silencers made of thin foil provide better soundproofing at low frequencies, as a result of the fact that low-frequency noise is emitted. This can be a problem in open setups near rooms. Another disadvantage is that the soundproofing effects decrease proportionally to the increase of the internal diameter. As alternative to silencers, double walled steel ducts can be used. These insulated ducts consist of a metal spiral seam inner and outer pipe separated by a layer of sound absorbing material. Soundproofing of these ducts can be achieved by using mineral wool as an insulator and perforating the inner duct. This will render the ducts eminently suitable for combined thermal and soundproofing. As a result of the thinness of the casing, the noise insulating value per linear meter is relatively low, in particular at low frequencies. The perforation level should be 13 to 15 %. The required length is at least 2 m for internal diameters up to 80 mm and 4 m for internal diameters up to 125 mm. These ducts can also be encased within concrete floors.

Simplified guideline for dimensions of silencers

Table 2: Indication of dimension for silencers

	Flow capacity q_v (m^3/h)	Diameter (mm) internal	Diameter (mm) external	Silencer length (mm)
ducts directly connected to rooms	$q_v < 100$	100	200	1000
	$100 < q_v < 250$	150	250	1000
ducts directly connected to other spaces	$q_v < 100$	100	200	750
	$100 < q_v < 250$	150	250	750

Acoustic properties of terminal devices

The A-weighted sound power level of grilles can be approximated by:

$$L_{W(A)} = -4 + 70\log v + 30\log \xi + 10\log S$$

Where:

v is the air velocity across the grille in m/s

ξ is the airflow resistance factor [-].

S is the surface area of the grille in m^2.

Supply grilles must be selected on the basis of the nominal sound power levels to meet the required noise levels. Manufacturers have various ways of indicating the acoustic data. They usually provide a manual to help select the grilles on the basis of their acoustic properties.
In general the maximum allowable sound power levels (L_w) of grilles will be:

- bedrooms: approx. 35 dB(A)
- living rooms:
  - one grille : approx. 35 dB(A);
  - two grilles : approx. 32 dB(A);
  - three grilles : approx. 30 dB(A).

Aerodynamic noise inside ducts

The following points must be observed in order to prevent aerodynamic noise:

- the maximum allowable air velocity in main ducts is 4 m/s and inside branch ducts to grilles 2 m/s;
- the use of round ducts is preferred;
- sharp bends should be avoided and changes of cross-sectional areas of ducts should be smooth;
- the system must be designed in such a way as to require the minimum number control valves; if the use of control valves cannot be avoided, these should be low-noise valves;
- if possible, control valves must be positioned in front of the silencers;
- air velocity inside the silencers must be such that the aerodynamic noise generated, is 10 dB lower than the ventilation noise immediately after the silencer; aerodynamic noise restricts the velocity of the air passing through the silencers to 4 to 5 m/s.

Fan location

Fans should be placed in a vibration-insulated position on the floor. Vibration insulation may be achieved by placing the four corners of the unit on rubber blocks, with a vulcanized plate, and provided with studs or other mounting facility. It is also possible to place the fan on elastic rigid mineral wool plates.

4. Sound transmission in or between dwellings

Requirements and methods of calculation and measurement

With respect to the sound requirements between two rooms, a distinction is made between rooms within the same dwelling on one hand and between one dwelling and another or between a room in a dwelling and a space outside it on the other hand. More stringent requirements apply to constructions which separate two adjacent dwellings.
There are many different ways in which the sound insulation requirements are expressed. In general for most countries the average sound reduction index R_m in the range between 125 and 2000 Hz for constructions between dwellings must be 50 to 52 dB. The sound insulation characteristic of a wall is usually expressed as the sound reduction index R. The sound reduction index R between two rooms can be evaluated from:

$$R = L_{ps} - L_{pr} + 10 \log S/A \quad [dB]$$

Where:

L_{ps} is the sound pressure in source room in dB
L_{pr} is the sound pressure in receiving room in dB
S is the surface area separating wall in m^2
A is the room absorption in m^2 sabine.

The sound reduction index R is the result of the different sound channels from one room to the other. This composite sound reduction index R' value is determined by:

$$R' = -10 \log \sum_{j=1}^{n} \frac{S_j}{S_{tot}} 10^{-Rj/10} \qquad [dB]$$

Where:

S_j is the surface area from one composure of the separating wall in m^2
S_{tot} is the total area of the separating wall in m^2
R_j is the sound reduction from one composure of the separating wall in dB

One of the sound channels may be a ventilation system. This phenomenon is also called cross-talk. Cross-talk can be defined as the effect that system components have on the integrity of the sound reduction between two rooms. Cross-talk is of particular concern in balanced ventilation systems and in collective air ducts between dwellings (such as central exhaust systems in residential buildings). It can be brought about in the following ways:

- through the air duct system; this phenomenon can take place both between rooms within the same dwelling and between rooms in two different dwellings;
- through the overflow grilles or openings underneath doors; cross-talk may occur in the case where two rooms have such openings near one another;
- through the duct transitions in walls or floors.

Cross-talk

There must not be a decrease of the sound reduction between dwellings as a result of the transfer of noise through shared ventilation ducts. Both natural (PSV) and collective mechanical ventilation duct systems usually require sound proofing provisions.
Such provisions may consist of:

- a silencer in front of each outlet or between outlets;
- a soundproofed grille at each outlet.

If, in dwellings, rooms are directly linked with one another by the supply duct of a balanced ventilation system cross-talk is a major point of concern. The effects of cross-talk in the system on the average sound reduction index is approximately 14 dB. In this case the overall sound reduction index value decreases and additional measures are necessary.
When doors are shortened at the bottom to facilitate air transport inside a dwelling (balanced ventilation and warm air heating), the following factors should be taken into account:

- doors must be shortened by 3 mm for each 10 m^3/h of air supplied to or removed from the room.
- if the doors of two adjacent rooms are directly beside one another, the sound reduction index of the separating wall must be higher than the minimum required value in order to compensate for the transfer of noise through the gap underneath the door.

A major point of concern are collective ventilation ducts (also PSV ducts) specially if they connect rooms in adjacent dwellings. Acoustic measures are in most cases necessary to maintain the required noise reduction. The total minimum insertion loss of a duct between two dwellings is given in table 3.

Table 3. Minimum insertion loss of a duct between two dwellings.

Frequency (Hz)	**125**	**250**	**500**	**1000**	**2000**
Insertion loss (dB)	0	0	10	15	15

Improperly constructed duct transitions may create acoustic leaks between the air duct and the separating wall. Soundproof connections between the duct and the separating wall are therefore recommended. These can be achieved by using a sealing glue or an airtight sealant.

References:

1. Månsson L.-G. (ed.), Annex 27 Evaluation and Demonstration of Domestic Ventilation Systems - State of the Art. Swedish Council for Building Research, Stockholm Sweden, 1995, ISBN 91-540-5731-0.
2. Recknagel, Sprenger, Hönmann, Taschenbuch für Heizung und Klimatechnik, Oldenburg Verlag, München Germany, ISBN 3-486-35913-4.
3. ISSO publication 28, Balanced ventilation in dwellings, Rotterdam the Netherlands, 1993, ISBN 90-5044-031-2.
4. ISO-Recommendation 1996, Assessments of noise with respect to community response, Technical Committee ISO/TN 43, 1971