Improvement of the acoustical performance of mechanical ventilation systems in dwellings: a case study

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ABSTRACT

The real performances of ventilation systems on site remains a challenge in practice. One of the most common reasons for complaints by the building occupants is the acoustic discomfort. Mechanical ventilation often produces too high levels of noise, mainly coming from the fans.

Although several good practice recommendations are theoretically known to limit the noise generation by mechanical ventilation systems, the acoustical performance of real ventilation systems on site seems uncontrolled and unexpected.

This paper presents a case study for the optimisation of a mechanical ventilation system in a dwelling. The aim was to identify points of attention for the improvement of both the acoustical and electrical performance of the system in practice.

The noise levels in the dwelling as well as the power input and the flowrates have been measured before and after several steps of optimisation of the ventilation system. The fan and the ductworks remained mainly unchanged.

The noise levels measured in the dwelling before the optimisation largely exceeded the requirements of the Belgian standard NBN S 01-400-1, for example 42 dB in the living room against 30 dB required.
After all the optimisation steps, the noise levels as well as the power input of the system significantly decreased. The main sources of improvement have been identified as the removal of acoustical dampers in the duct behind the air terminal devices, the replacement of externally mounted air transfer devices and air terminal devices with lower pressure drops, and better adjustment of the air terminal devices. Adding primary sound attenuator to the part of the ductwork which was not yet equipped allowed to further improve the acoustic performances in the rooms.

This case study demonstrated that large improvements of the acoustical and electrical performances of the mechanical ventilation system were possible with only limited modifications and keeping the fan and the ductwork mainly unchanged.

KEYWORDS

Noise level, sound attenuator, pressure drop, airflow adjustment

1 INTRODUCTION

The real performances of ventilation systems on site remains a challenge in practice. One of the most common reasons for complaints by the building occupants is the acoustic discomfort. In some extreme cases, the noise levels are so high that the occupants switch off the ventilation system, possibly leading to insufficient ventilation and poor indoor air quality (IAQ). Mechanical ventilation often produces too high levels of noise, mainly coming from the fans, but also noise generated by the airflow in ducts and components.

In Belgium, the standard NBN S 01-400-1 [1] sets maximum noise levels for the technical installations such as mechanical ventilation (Table 1). Some on-site measurement campaigns showed usually (extremely) too high noise levels in dwelling due to the ventilation system [2] [3]. Although several good practice recommendations are theoretically known to limit the noise generation by mechanical ventilation systems, the acoustical performance of real ventilation systems on site seems uncontrolled and unexpected.

This paper presents a case study for the optimisation of a mechanical ventilation system in a dwelling. The aim was to identify points of attention for the improvement of both the acoustical and electrical performance of the system in practice.

The noise levels in the dwelling as well as the power input and the flowrates have been measured before and after 4 steps of optimisation of the ventilation system. The fan and the ductworks remained mainly unchanged.

Table 1: Requirements for the standardized service equipement sound pressure level $L_{Ainstal,nT}$ in the Belgian standard NBN S 01-400-1 for mechanical ventilation systems in dwellings

Type of room	**Maximum $L_{Ainstal,nT}$ for normal acoustic comfort (dB)**	**Maximum $L_{Ainstal,nT}$ for enhanced acoustic comfort (dB)**
Living room	30	27
Bedroom	27	25
Bathroom	35	30

2 MATERIAL AND METHODS

2.1 Presentation of the dwelling

The studied dwelling is a semi-detached house built in 2016 and composed of a living room, an open kitchen, 3 bedrooms, a bathroom, 2 toilets and a garage.

The ventilation system is a balanced mechanical ventilation system with heat recovery. The system can be manually controlled using 3 fixed flowrates of around 300 m³/h (nominal flow rate), 190 m³/h and 100 m³/h.

The ventilation unit is installed in the garage, which can be considered as a separated technical room. The ductwork is branched and composed of rigid metal ducts. The ducts are sized to limit the air speed below the recommended values of 2 m/s, 4 m/s and 6 m/s in the terminal ducts, the secondary ducts and the main ducts respectively. Primary sound attenuators were present only on some main duct sections, but not all (see below). Additional in-duct foam sound attenuators were situated just behind the 2 air terminal devices (ATD) of the living room.

2.2 4 steps of optimisation

In the initial situation, the ventilation system satisfied some good practice recommendations for the design and installation of ventilation systems [4], such as:

- The ventilation unit was installed in a separated and closed technical room;
- The sizing of the ducts was carried out to limit the air speed below the recommended values;
- Primary sound attenuators were present on some main duct sections (but not all).

On the other hand, some possible improvements have been identified, with possible impact on the acoustical performances of the system. These improvements have been carried out in 4 steps as described hereafter.

Step 1: Removal of the in-duct foam sound attenuators behind the air terminal devices

The foam sound attenuators (Figure 1) behind the ATD's of the living room were probably used to reduce the noise level coming from the fan and the ductwork and probably also to limit the noise transfer between different rooms connected to the same duct part. However, such foam sound attenuators can cause higher pressure drop in the ductwork. In the first step, these foam sound attenuators have been removed.

Moreover, some ATD's seemed to have been adjusted to a particularly closed setting. In addition, none of the supply ATD's seemed in a fully open setting. A new adjustment of the ATD's has been carried out [4] [5] in order to reduce as much as possible the pressure drop generated by the air terminal devices. To illustrate the potential of this new adjustment: the most open supply ATD was set to an opening position of 20 mm after this new adjustment compared to 8 mm in the initial situation.

Figure 1: Foam sound attenuator initially used behind the ATD of the living room.

Figure 2: Comparison of the externally mounted air transfer devices before (right) and after (left) optimisation in step 2.

Step 2: Replacement of the externally mounted air transfer devices

The second improvement was the replacement of the externally mounted air transfer devices used for the intake of outdoor air and the exhaust of air outside the building. The components initially mounted in the façade have been replaced by components with a larger area (Figure 2). The calculated pressure drop through these components for the nominal flow rate (300 m^3/h) was 21 Pa for the new component compared to 117 Pa for the component initially used, i.e. 5 times lower.

Step 3: Replacement of some air terminal devices

For step 3, some of the ATD's have been replaced by other components generating less pressure drop, especially in the sections of the ductwork with the highest pressure drop. For example, based on the data from the manufacturer of the air terminal devices, the replacement of the ATD in the living room should reduce the pressure drop of the ATD to 10 Pa compared to 80 Pa for the initial situation (at a flow rate of 70 m^3/h).

After this replacement of ATD's, a new adjustment of the flow rates at the ATD's has been carried out.

Step 4: Adding some primary sound attenuators

As mentioned above, some part of the ductwork was initially not equipped with primary sound attenuators. A new primary sound attenuator has been added on the main duct section connected to the living room and 2 of the bedrooms. A second sound attenuators has also been added on the duct connected to the main bedroom in order to achieve higher acoustical comfort in this room. Both sound attenuators have a length of 0.9 m and a thickness of sound attenuation material (mineral wool) of 5 cm.

Because the ductwork has been slightly modified, a new adjustment of the ATD's has been carried out.

2.3 Measurements before and after each step

Before and after these steps, measurements have been done, for the fan setting 3 (nominal flow rate) and fan setting 2, as follows:

- Flow rates in the rooms;
- Electrical power absorbed by the ventilation unit;
- Noise levels in the rooms (except after step 2).

The flow rates have been measured at the ATD's using a zero pressure compensation measurement device (Flow Finder, ACIN, NL).

The electrical power absorbed by the ventilation unit has been measured using a power meter to place directly into the electrical plug (Christ Elektronic, DE).

The standardized service equipment sound pressure levels LAinstal,nT in the rooms have been measured according to the standard ISO 10052 [6]. The equivalent sound pressure levels were measured over a time interval of 30 s in three positions (two in the reverberant field and one in a corner) using a handheld sound level meter (Bruel & Kjaer, type 2270). The levels were standardized with the average reverberation time in the octave bands of 500 Hz, 1000 Hz and 2000 Hz.Results

2.4 Flow rates

The flow rates have been measured in the initial situation and after each optimisation step. In the initial situation, the flow rates in all the rooms were conform the requirements of the EPB regulation in Belgium, except in the main bedroom with 66 m^3/h compared to 68 m^3/h (97%) and in the living room with 114 m^3/h compared to 142 m^3/h (80%). During the first optimisation step, the flow rates have been corrected to be conform the requirement.

After the different optimisation steps, the total flow rates slightly varied but remained of the same order, indicating equivalent performances of the system in terms of indoor air quality (Figure 3).

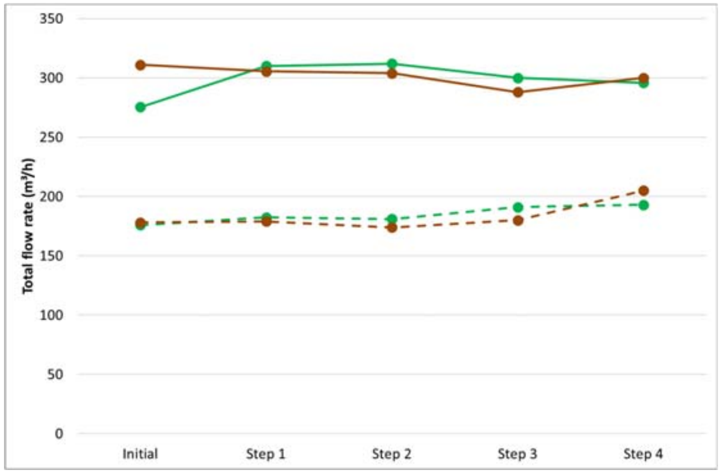

Figure 3: Evolution of the total flow rate from the initial situation and after the 4 optimisation steps, for supply (green) and extraction (red), for fan setting 3 (nominal setting, full lines) and fan setting 2 (dotted lines).

2.5 Noise levels

The standardized service equipment sound pressure levels have been measured for the initial situation and after optimisation step 1, 3 and 4 (step 2 was not measured) and compared to the requirements of the Belgian standard NBN S 01-400-1 (Figure 4). The specific service equipment noise levels have also been calculated by correcting the measured service equipment sound pressure levels for background noise according to clause 8 of ISO 16032 [7]. The background noise was measured when the ventilation system was switched off.

For the initial situation and nominal fan setting, the noise levels largely exceeded the requirement of the Belgian standard for normal acoustic comfort in all the rooms, except in the bathroom that was conform. For example, the noise level in the living room was 42 dB compared to the maximum allowed 30 dB; in the bedrooms the noise levels were between 39 and 40 dB compare to the maximum allowed of 27 dB.

After each optimisation step, the noise levels were decreased in the different rooms. For example after step 1, the noise levels were lowered by 7 dB in the living room and by 5 to 8 dB in the different bedrooms. After step 4, the noise levels in the different rooms were all conform the requirement of the Belgian standard for normal acoustic comfort and even for enhanced acoustic comfort in the living room, bedroom 1 and the bathroom.

For fan setting 2, the noise levels were lower compared to fan setting 3 and were conform the requirement for normal acoustic comfort in all the rooms for the initial situation as well as after optimisation. Due to the lower ventilation noise levels for fan setting 2 (especially after optimisation), the measurements were generally influenced by background noise. For these low noise levels, the specific installation noise levels better represent the noise coming from the ventilation system and give an upper limit of the service equipment sound pressure levels. For fan setting 3, background noise was only an issue after optimisation step 4.

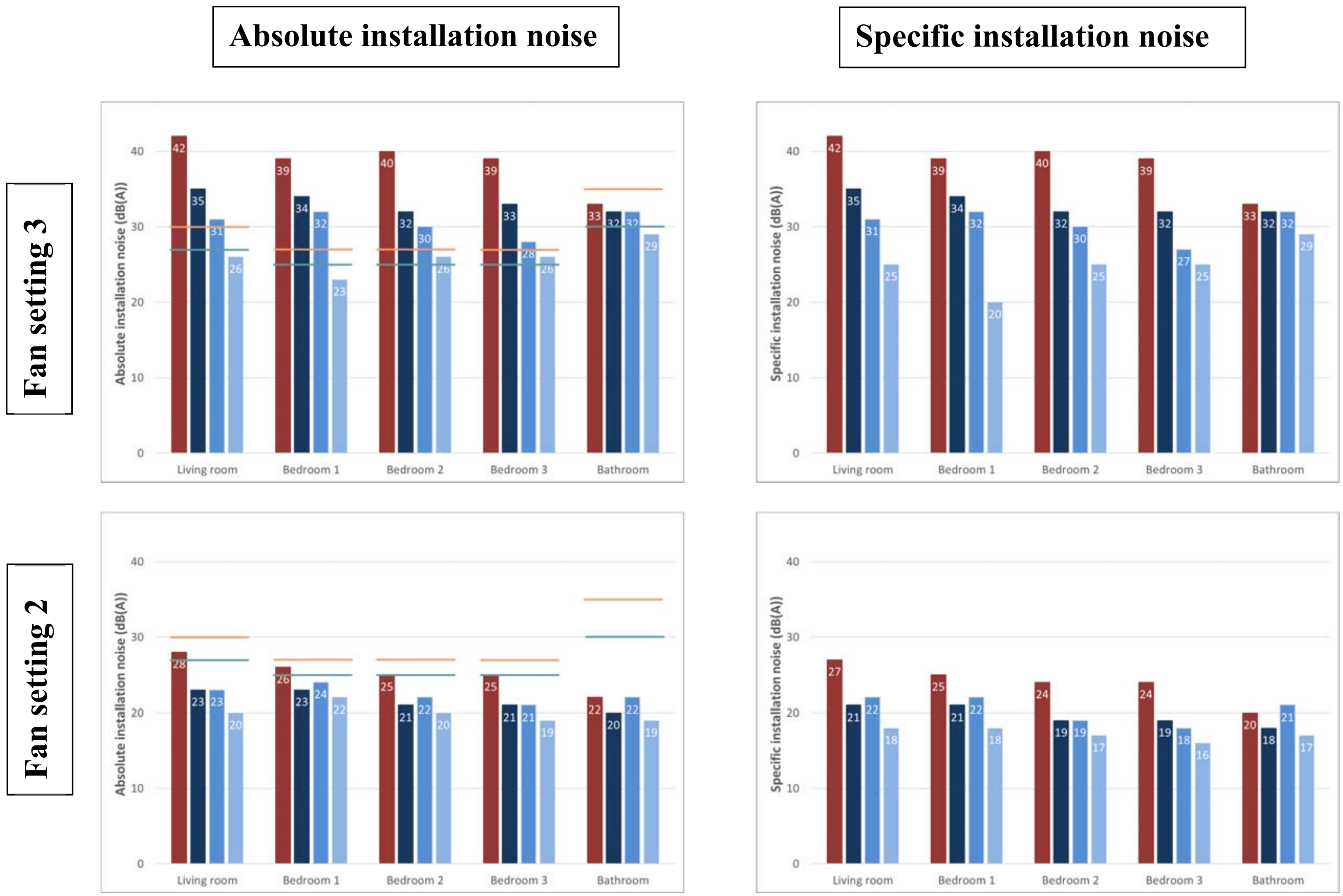

Figure 4: Standardized service equipment sound pressure levels without (left) and with (right) background noise correction for the initial situation and after optimisation step 1, 3 and 4 (step 2 was not measured) for fan setting 3 (nominal setting, above) and for fan setting 2 (below). The requirements of the standard NBN S 01-400-1 are indicated in orange (normal acoustic comfort) and in green (enhanced acoustic comfort).

2.6 Electrical power

The electrical power absorbed by the ventilation unit has been measured for the initial situation and after each optimisation step. The Specific Fan Power has been calculated for the whole unit as follows:

$$SFP\ (W/(m^3/h)) = P\ (W)\ /\ q_{min}\ (m^3/h) \quad (1)$$

Where:
P is the total electrical power absorbed by the ventilation unit;
q_{min} is the lowest value of the total measured flow rate for supply and total measured flow rate for extraction.

The electrical power as well as the calculated SFP decreased significantly from the initial situation and after each optimisation step, except after step 4 where a slight increase was observed (Figure 5). These reductions were higher for the nominal fan setting (3) than for fan setting 2. From the initial situation to step 4, the reduction of the electrical power was 39% for fan setting 3 and 13% for fan setting 2; and the reduction of the SFP was 37% for fan setting 3 and 25% for fan setting 2.

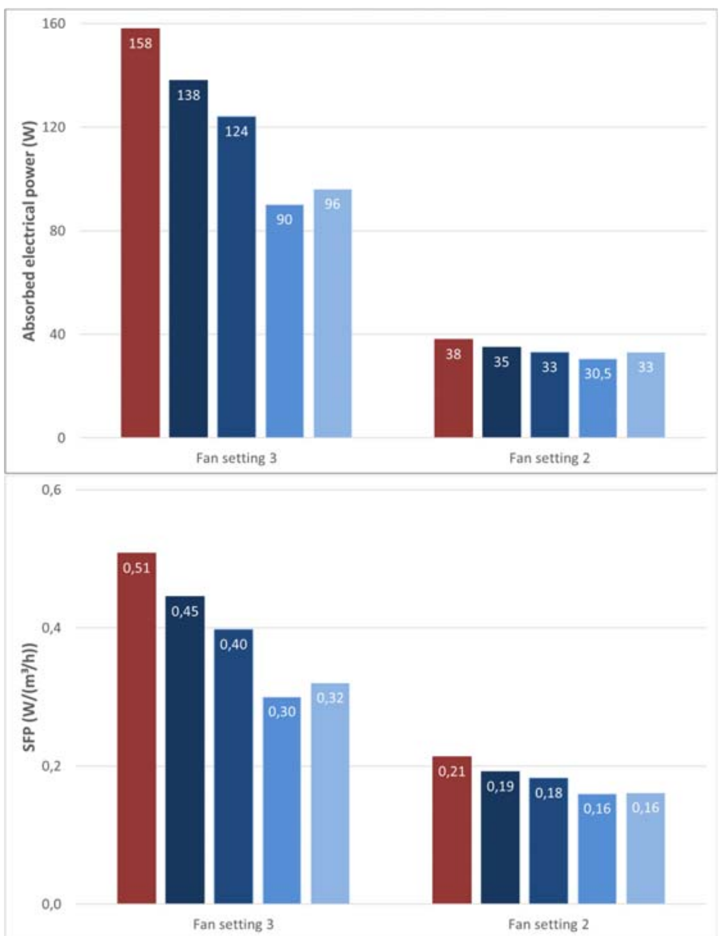

Figure 5: Electrical power absorbed by the ventilation unit (above) and Specific Fan Power (below) for the initial situation (red) and after the 4 optimisation steps (blue).

3 DISCUSSION

Some good practice recommendations had been followed in the dwelling of this case study, such as placing the ventilation unit in a separated closed technical room, sizing of the ducts to limit the air speed, and the use of primary sound attenuators (but not for all rooms in this case). However, the noise levels in the rooms were very high and largely exceeded the requirements of the Belgian standard NBN S 01-400-1, leading to dramatic acoustic discomfort for the occupants of this dwelling.

This indicates that, beside these good practice recommendations, other aspects of the ventilation system can have a negative impact on its acoustic performances. The results of the optimisations from step 1 to step 3 allow to identify some of these aspects as detailed hereafter.

3.1 Pressure drop

The use of the foam sound attenuators situated behind the ATD of the living room could theoretically attenuate some noises coming from the ducts of these ATD. However, the removal of these foam sound attenuators in step 1 (together with a new adjustment of the air flow rates at the ATD) allowed to reduce drastically the noise level in the living room, but also in other bedrooms connected to the same fan but not equipped of such foam sound attenuators. This can be explained by the high pressure drop generated by these foam sound attenuators. The removal of these components leads to a lower pressure drop in the ductwork, as evidenced by the decrease of the electrical power absorbed by the ventilation unit at the same time. The reduction of the pressure drop by the removal of these components can have two positive impacts on the acoustical performances. First, these components themselves probably generated noise because of the airflow through them. Second, the lower total pressure drop in the ductwork allowed decreasing the fan speed (to obtain the same flow rate) and thus decreasing the noise generated by the fan itself. This can be confirmed by the reduction of noise also in the 3 bedrooms which were not equipped with such foam sound attenuators.

The replacement of the externally mounted air transfer devices in the façade in step 2 showed also an improvement of the acoustic performances in all the rooms. This replacement was also associated with a decrease of the pressure drop generated by these components, as also demonstrated by the decrease of the electrical power absorbed by the ventilation unit at the same time. The pressure drop 5 times lower for the new component compared to the initial one (calculated based on the manufacturer data) can be explained by the larger free section for the airflow in the new one compared to the initial one, as evidenced in Figure 2. In this case, the decrease of the pressure drop applies centrally for the fans (and not locally), allowing also decreasing the fan speed.

Finally, a better adjustment of the ATD's (step 1 and 3) and the choice of low pressure ATD's (step 3) allowed also to reduce slightly the noise levels in the rooms. Again, this can be explained by a decrease of the pressure drop in the system allowing the fan to run at a lower speed and then generating less noise. These steps were also associated with a reduction of the electrical power. The choice of low pressure ATD is particularly important for the duct parts where the pressure drops are the most unfavourable. The adjustment of the airflow rates at the ATD is a very important step of the commissioning of a ventilation system. The Belgian Building Research Institute developed recently a methodology and a tool [5] to facilitate this adjustment for ventilation systems in dwelling, assuring to achieve a good result within a limited work time. In this adjustment procedure, it is very important to keep in mind that at least one ATD should remain in a fully open setting position in order to decrease as much as possible the pressure drop of the whole system. The ATD remaining in fully open setting position is those corresponding to the duct part with the most unfavourable pressure drops.

3.2 Primary sound attenuators

After step 3 and the above-discussed optimisations, the noise levels had been improved compared to the initial situation but remained too high in some rooms, especially the living room, bedrooms 1 and 2. The specific installation noise level in bedroom 3 was significantly lower (27 dB) compared to those in the other rooms (30 to 32 dB). Bedroom 3 was the only room connected to a duct part equipped with a primary sound attenuator.

In step 4, a primary sound attenuator has been added to the duct part delivering the living room, bedroom 1 and bedroom 2. Moreover, an additional sound attenuator has been installed to further protect the main bedroom 1. Between step 3 and step 4, the noise levels decreased by 5 dB in the living room and 4 dB in bedroom 2, demonstrating the significant positive impact of a primary sound attenuator. The noise reduction was even higher, by 9 dB, in bedroom 1, because of the additional sound attenuator in this room.

Note that the electrical power absorbed by the ventilation unit slightly increased after step 4 compared to step 3 because a part of the ductwork was modified in order to add the sound attenuators and was slightly longer compared to the initial situation (this could have been avoided if the sound attenuators had been integrated initially).

4 CONCLUSIONS

The acoustic performances of mechanical ventilation systems in dwelling remain a challenge in practice. The present case study confirms the relative difficulty to achieve high acoustic performances in dwelling because some small design errors can have dramatic impact.

The results confirm the importance of the following measures to achieve high acoustic performances of ventilation systems in dwellings:

- Placement of the ventilation unit in a separated closed room (technical room);
- Sizing of the ducts to limit the air speed below the recommended values;
- Use of primary sound attenuators close to the ventilation unit for all the duct parts and with sufficient attenuation performances (length, thickness of attenuation material).

Beside these acoustic recommendations, the global quality of the ventilation system is also very important to ensure the final acoustic performances. Limiting the pressure drops in the system is particularly important in order to avoid flow noise generation due to a high pressure drop in some component, but also to allow the fan to run at a lower speed for which the generated noise is lower.

Some small sound attenuators to be placed behind the air terminal devices, such as foam components, have to be used carefully because the additional generated pressure drop can have a more negative impact on the acoustic performances than the theoretical attenuation of the component.

Following these recommendation, it is possible to fulfil the acoustic requirements, such as 27 dB in the bedrooms (normal acoustic comfort in the Belgian standard). Higher acoustic performance can be achieved by using additional sound attenuators, for example for sensitive rooms such as bedrooms.

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