ENERGY SAVING WITH SILENCERS IN VENTILATION SYSTEMS

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Noise and acoustic environment conditions affect health, well-being and performance inside and outside of work and living spaces. Therefore, standards have to be met in buildings just as for the other room features light, climate and air quality. While energy-saving lamps and energy-efficient air conditioning systems are obvious considerable reserves still exist in the sound-absorbing components. They are obstacles to the air transport and the effort to overcome this resistance has to be provided in terms of energy by increased power of fans. Thus, in its optimized configuration lies potential for energy savings while improving the acoustic quality. The article analyzes the acoustic boundary conditions taking into account the effects of energetic consequences in the use of silencers. Solutions for their design will be presented and demonstrated with examples of achievable energy savings. As a kind of a flagship project serves a painting facility: Only through the exchange of conventional by innovative silencers in a large industrial air conditioning system it was possible to reduce both noise pollution and to achieve an annual energy savings worth more than 500 000 Euro. In this way, innovative silencers link high, appropriate attenuation effects to low flow resistance, expressed by the pressure loss. The high amount in this sample system is certainly exceptional due to the plant dimension, but also on a small scale systematical and cost-effective synergies can be achieved.

1. Initial situation

Noise and acoustic environment conditions affect health, well-being and performance inside and outside of work and living spaces. Therefore, standards have to be met in buildings just as for the other room features light, climate and air quality. While energy-saving lamps and energy-efficient air conditioning systems are obvious considerable reserves still exist in the sound-absorbing components. They are obstacles to the air transport and the effort to overcome this resistance has to be provided in terms of energy by increased power of fans. Thus, in its optimized configuration lies potential for energy savings while improving the acoustic quality. The article analyzes the acoustic boundary conditions taking into account the effects of energetic consequences in the use of silencers. Solutions for their design will be presented and demonstrated with examples of achievable energy savings.

2. Interaction of Noise Control and Energy Efficiency

Energy consumption and noise emission from air conditioning systems are assessed differently depending on the point of view and on specific date. At the investment decision, measures to
reduce energy consumption are clearly established with payback. The cost of noise reduction, however, is considered to be 'only' cost-intensive. The assessment is often reversed at a later during operation. Users of ventilated rooms or neighbors of industrial ventilation systems may be aware of their energy efficiency, but the disturbance of ventilation noise is acute and chronic.

In terms of high energy efficiency of buildings, air conditioning and forced ventilation are current measures to minimize the heat losses of office and private buildings. In industrial plants process air is an essential component so that all types of buildings are nowadays equipped with fans for air supply. Therefore, they represent also the essential sound source whose noise occurs at the air intakes and outlets. For those facilities that are subject to authorization there are for example the German TA Lärm and the DIN 4109 defining requirements of the allowed rating level or sound pressure level. Usually, they are defined as singular values, which do not allow drawing conclusions on the kind of noise and its annoyance.

Figure 1 (left) shows the typical noise frequency range of fans, focusing at low frequencies. For comparison, the picture shows (right) also the attenuation capacity of conventional silencers, which reaches its maximum at mid and high frequencies. These silencers usually consist of mineral wool blocks whose surfaces are covered by a trickle protection and perforated sheets.

![Figure 1. Typical spectrum of fan noise (left) and attenuation spectra of conventional as well as adapted (innovative) silencers (right).](image)

Applying these silencers the low-frequency sounds emerge even at low levels, which are in turn considered very disturbing. With the product of speed and number of blades of the fan (relative to 1 s) a tonal noise may occur in addition, which is known as rotation sound that is much louder than the rest of the fan noise. This so-called tonal component is strongly perceived due to its information content and classified as extremely annoying if it is not damped accordingly. The rotation sound requires a high and customized attenuation, which conventional silencers typically do not provide. To achieve sufficient attenuation with this type of muffler despite this "acoustic mismatch", thick and long splitter silencers with almost closed air gaps in between are installed, resulting in a corresponding high pressure drop. Thus, silencers with an attenuation spectrum adapted to the low-frequency noise of the fan could better fulfill not only the acoustic requirements. They can also improve the energy efficiency of the ventilation system in a slimmer version and with larger air gaps in between. Distributed soundproofing installations, such as in duct bends, lead into the same direction as an improved acoustic effect is reached with the same material effort.

Thus, a clear interaction between acoustic and energy efficiency can be justified. Its importance is increasing, because the savings are not at all in a negligible range. On the contrary, in the example shown in detail below for a larger painting shop with approx. 1 million m³/h exhaust
The annual energy savings can be more than 7000 MWh, if more appropriate components are used instead of conventional silencers. Apart from the production and acquisition costs, these soundproofing installations cause also other running costs. Just in process air systems, particles etc. are present in the exhaust stream which more or less quickly adhere to surfaces. This effect causes deposits at or partially in porous or fibrous silencers that strongly affect the acoustic functionality after a certain period. It is not uncommon that nuisance from noise then occurs in new plants after one or two years operation. Large plants are therefore regularly monitored by means of acoustic measurements in order to clean or replace the silencers in time. These procedures are also expensive and environmentally questionable, so acoustically and energetically efficient silencers should be in addition pollution-resistant and cleanable.

It may be referred at this stage to a different context between sound insulation and energy efficiency associated with exhaust systems. Increasing the energy efficiency of these devices and systems is associated with technology impacts that interfere with a practical implementation. As an example, modern heaters produce more noise and condensate than in the past. Noise reduction methods proven so far are limited in their functionality and components soaked by condensate fail and cause hazardous waste. Technological solutions have to be found for these after-effects.

3. Acoustic and energetic characteristics of silencers

So far the aerodynamic and acoustic treatments of silencers in air ducts are separated. Therefore, mutual optimization takes place at best by "Trial and Error", especially as the conventional silencer splitters are offered and considered when planning mostly in a few standard sizes, such as with a width of 100 and 200 mm. At least, all (quality controlled) manufacturer catalogues for this kind of silencers include by default measurement of pressure loss data in addition to the measured attenuation. As shown in Fig. 2, simple splitter silencers consist of a duct segment where single splitters are installed symmetrically. These usually consist of a sheet metal frame, which is filled with porous absorber material, such as mineral wool. Protective layers of cloth and perforated sheet may be attached on the open and sound-absorbing surfaces.

Aerodynamically-related energy consumption due to pressure loss of such silencers in the air flow can be determined in a simplified manner with the calculations shown in Fig. 3. After that, the main factors are the respective volume flow of the system, as well as the relation of splitter width to air gap width (see also Fig. 2).
Pressure loss coefficient
\[
\zeta = 0.65 \frac{d}{s} + 0.025 \frac{L}{2s} + 0.53
\]

Pressure loss in Pa
\[
\Delta p = \zeta \frac{1}{2} \rho \nu_s^2
\]

Energy consumption in MWh/a
\[
E_{\Delta p} = 3.25 \zeta \frac{\mu}{\eta} \frac{\rho}{\rho_0} \frac{Q_v}{Q_0} \left(\frac{\nu_s}{v_0}\right)^2
\]

- \(d\): half splitter width (m)
- \(s\): half air gap width (m)
- \(L\): splitter length (m)
- \(\rho\): air density (kg/m³)
- \(\nu_s\): flow speed in the air passage (m/s)
- \(\mu\): operating ratio of the fan (h/day)
- \(\eta\): efficiency of the fan
- \(q_v\): volume flow (m³/s)

\[
\rho_0 = 1.21 \text{ kg/m}^3
\quad q_0 = 10 \text{ m}^3/\text{s}
\quad v_0 = 10 \text{ m/s}
\]

**Figure 3.** Simplified calculation of pressure drop and energy consumption per year.

Calculating the insertion loss as relevant acoustic parameter of silencers is more elaborate and it is referred to different articles\(^1\),\(^2\) at this point. From these it is apparent that also the parameter ratio splitter to air gap width and in addition the length of the splitter affect significantly the attenuation result. For conventional silencers made of porous or fibrous materials the acoustic effect depends additionally on the material. Because the practice is dominated by mineral wool slabs, there is only little scope available.

The variation of both the aerodynamic and acoustic effects influencing factors (splitter and air gap width), however, shows a very different sensitivity. The example in Fig. 4, where the impact is considered for a slightly modified air gap and otherwise same conditions, illustrates these differences. Underlying parameters are an exhaust volume flow of 200000 m³/h, a duct cross section of 2 x 2 m², where conventional silencer splitters are installed with a width of 200 mm and with 1 m in length. The assumed fan with an efficiency of 85% works in continuous operation (\(\mu = 1\)).

**Figure 4.** Energy consumption of air exhaust system caused by the pressure loss of silencers as a function of air gap width (left). Insertion Loss results due to a variation of the air gap width by 10 mm (right).

In the energy consumption diagram (Fig. 4 left) the reduction is highlighted that is obtained if the air gap is just widened by additional 10 mm. This little “inaccuracy” is generally ignored during the actual implementation of very large installations. The potential energy savings of approximately 24 MWh/a is however by no means negligible and in larger systems, this saving can be significantly higher. The acoustic difference manifests itself at 10 mm further increased air gap in the range of...
1 dB, depending on the noise spectrum of the fan. This value is very small and commonly considered as accuracy tolerance for the planning and measurement.

4. Integral solutions

Most commonly applied are passive silencers (Fig. 5 left) either as splitter silencers or as tubular mufflers.\(^3\) With the lowest cost, a high attenuation at mid and high frequencies is obtained as illustrated in Fig. 1 (right). However, their attenuation is not sufficient at low frequencies where the noise spectra of fans are often dominant, so that already today other, more customized silencer principles are offered. Resonance silencer\(^4,5\) are represented in Fig. 5 whose attenuation can be adjusted to a required noise spectrum. Either mass-spring-systems or hollow chambers (such as Helmholtz resonators) are used, still allowing the application of different constructions.

![Silencer principles](image)

Figure 5. Silencer principles in a splitter type design.

Due to their higher acoustic efficiency, leaner silencer with a lower pressure drop and energy consumption can be used at the same noise reduction. Currently, these silencers are still slightly more expensive than the passive components, although they can be cleaned almost completely, an enormous advantage just in process air technology. But also combinations of mineral wool and resonance type silencer are used in certain cases where the fan noise is very broadband.

Regardless of silencer type the pressure loss should also be minimized by construction. On the one hand inlet nose profiles\(^6\) are helpful for reducing quite considerably the obstacle for the air flow and thus the pressure loss. Simple designs such as half-circle profiles cause only minor additional costs and do not affect the acoustic properties. However, this obvious possibility of saving energy is much too rarely used. One reason for this may be the missing offer for a clear cost-benefit calculation.

If on the other hand only thick silencer splitters (with or without flow profiles) combined with small air gaps deliver the necessary attenuation result, pressure loss will increase enormously. A way to again increase the overall cross-section of all air gaps is the widening of the duct over the splitter silencer length. This means that for a quite typical installation situation where splitter and air gap width are equal, the duct width must be doubled. This consumes considerable space with corresponding structural consequences and requires twice the number of silencer splitters in this example. Both these aspects are highly affecting the costs. However, such extensions are much more often taken into consideration and implemented as customized, innovative silencers whose potential is by far not yet exploited.
5. Design and calculation

Planning and calculation tools represent an inevitable necessity to allow for the increasing complexity in the design of an air supply system taking into account the acoustic and energy constraints. When planning, especially the pipe or duct routing, cross sections and the resulting flow velocities play an important role. During the design of noise reduction measures, the acoustic and energetic properties of the components have to be linked and aligned. In this context, some parameters, such as splitter and air gap width, play a central role as they both contribute to improving both areas considerably. It makes matters even worse that due to the large number of parameters and principles of the silencers multiple solutions may be generated with very different characteristics. Surprisingly, the determination of an optimum of all applicable aspects by means of a computer program has not been pursued previously and represents a challenge for future research projects and software developments.

Apart from the (measurement) databases of the manufacturers of silencers several programs were developed at the Fraunhofer IBP that can calculate the acoustic properties of conventional and alternative silencers. Figure 6 shows the program CompAS for conventional silencers, which is also capable of determining the intrinsic flow noise, pressure loss and the resulting energy consumption.

![Figure 6. Program CompAS for passive silencers (left) and calculation program for the acoustic design of duct networks (right).](image)

Implementing different silencer types in distributed systems is already more advanced because these calculation methods are well validated and can be integrated with little effort. An example shows the software RLTA of the Fraunhofer IBP also in Fig. 6, in which individual parts are graphically arranged and linked together. The elements can be called from an extensible library and their properties adjusted to the required conditions. As a result, the acoustic transmission behaviour of the coupled total system and the resulting attenuation are available.

In addition to the previously mentioned ways to achieve acoustically and energetically optimized noise reduction with customized silencers and appropriate constructive solutions, other approaches may be noted that would be possible and useful for a broad application in practice. These are for example elbow silencers with higher attenuation than comparable straight ones, lined ducts with probably low attenuation, but obtaining the required attenuation over large lengths with significantly reduced pressure loss, as well as the use of reflection loss at vents and cross section changes. These effects can reduce elsewhere silencers and hence pressure loss when accounted for precisely and are at least in part together with other components, such as optimized fire dampers, integrated already in the software RLTA.

6. Application example

This section refers to experiences and individual projects which were initiated and coordinated by the IBP. In the foreground are (unfortunately) a few, but current case descriptions, where on
the one hand acoustically and energetically optimized solutions were practically applied. On the other hand, it is a characteristic of these examples that an adequate effort for planning and validation of the energy consumption was invested. In this process emerged the tools, which are understood as precursor for a future accurate and reliable acoustic-energetic assessment of process air systems.

So to speak as a lighthouse serves a painting plant of Daimler AG in Düsseldorf (Mercedes Sprinter series) with the considerable air volume flow of 1.1 million m³/h. The plant was initially equipped with "normal" mineral wool sound absorbers and came apparent some years ago by gradually increasing noise in the adjacent residential area.

Between the years 2003 and 2005 the noise levels increased by nearly 10 dB, a clearly audible difference in any case. Root cause analysis brought to light sooted, bonded, and thus for the acoustics partially sealed perforated sheets of the silencer. This was the starting point of a systematic revision in acoustic terms, where the enormous energy costs also led to openness with regard to energy-saving silencers.

![Image: Design of the 20 m-long resonance silencer in the exhaust duct of a plant component](image)

**Figure 7.** Design of the 20 m-long resonance silencer in the exhaust duct of a plant component.

However, the acoustic-energetic balance sheet was developed and optimized in a way too. As result resonance type exhaust silencers were employed acting as plate resonators (stainless steel membranes) in different variations, see Fig. 8. Their great additional advantage is the much simpler cleanability compared to passive silencers covered with perforated sheet metal and a considerable extension of the service life.

As a result of adjustment and replacement of the silencers, following figures from the before and after comparison can be ascertained:

- **Noise reduction:** at required level of LwA 86 dB(A)
- **Reduction of energy consumption:** 7600 MWh per year
- **Reduction of CO2 emissions:** 3020 tonnes of CO2 per year
- **Reduction of energy costs:** > 500 000 € per year

Even without taking into account the future cost savings in cleaning and replacement, which indirectly also avoids energy consumption, the reduced energy costs lead to return on investment within a very short time.

Similar results were achieved in exhaust ventilation system projects of Odenwald fibreboard plant Amorbach (OWA) and Saint-Gobain Isover AG in France. Reproducible effects where thus obtained also in practical applications, albeit with still unpredictable output concerning the optimized solution for the respective plant in both terms (acoustics and energy) due to a lack of experiences and the absence of powerful planning tools.
7. Conclusion and Outlook

For the energetic and acoustic planning and realization of sound absorbing installations, as practised today, the following consequences may be derived:

- The constructive and air technical influencing parameters affect both the energy and the acoustic effect of sound absorbing installations.
- The intensity of these effects and their interactions with each other are different depending on the parameter (-combination).
- Seemingly negligible details and "uncertainties" can have serious consequences in terms of the efficiency of energy and acoustics alike.
- A tightly coupled optimization and clarification of both aspects during planning, design and execution is required to unlock potential savings. This requires first and foremost combined and validated calculation tools.

In today’s approach, the integral analysis of acoustics and energy efficiency is not a standard in the planning and operation of HVAC and process air systems. Just this synergy offers enormous potential for further energy savings with enhanced acoustic quality in the sense of sustainable buildings and production facilities. Future R&D requirement therefore focuses on practical deepening of the existing theoretical knowledge, to create efficient methods and tools for design, planning and evaluation of acoustic-energetic efficiency. Furthermore, great importance lies in the development of optimized system and design concepts, as well as highly effective components and materials.

In the end, the optimization of energy costs has to be proven by comprehensible before and after comparisons in more pilot plants. This allows moving the previously sole focus on investment to the savings of operating costs through new technology.

REFERENCES