ACTIVE CONTROL FOR THE PURPOSE OF ENERGY EFFICIENCY: WHEN BEING QUIET CAN MEAN BEING GREEN

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Commercial active noise control systems are often evaluated only according to their acoustic benefit. While this benefit is often justification for a system purchase, there can also be significant energy savings as a result of the use of active control systems. This paper describes two commercially-available HVAC active noise control systems that can be used to meet customer acoustic requirements with a reduction in air handler power consumption. A near-zero-pressure loss active muffler system for internal combustion engines is also described. In each case, we compare the power consumption or efficiency of the disturbance source for the passive and active cases. Only by considering energy consumption and savings can the true value of the use of active control be determined.

1. Introduction

Passive HVAC silencing units are traditionally relied upon to meet customer and/or municipal requirements during the building construction process. It is often overlooked that the noise attenuation provided by passive silencers has a corresponding pressure drop. It is common practice to then increase the power to the prime mover to compensate for this introduced inefficiency.

Active HVAC silencing has two distinct advantages over traditional passive methods. First, the flow footprint of an active silencer is comparably less - resulting in a lower introduced inefficiency. Secondly, the electronic tenability of active control allows the surgical removal of unwanted sounds. This can be contrasted to instances where passive silencers over-achieve in certain bands to meet the requirements in another.

This paper reviews two existing commercial active silencers with the additional consideration of energy efficiency. While traditionally overlooked, energy efficiency is possibly the most important consideration for the use of active silencing.

2. Silencing with commercially-available HVAC silencers

During the course of building design and construction, HVAC engineers are expected to provide an air handling system that – in addition to meeting basic ventilation needs - meets either customer or municipal noise requirements. Table 1 shows an example of real duct output noise requirements as established by a professional HVAC contractor and provided in the course of a duct silencing program.
Table 1. Measured noise level and estimated quieting.

<table>
<thead>
<tr>
<th>Noise level per test 006 (dB)</th>
<th>63Hz</th>
<th>125Hz</th>
<th>250Hz</th>
<th>500Hz</th>
<th>1000Hz</th>
<th>2000Hz</th>
<th>4000Hz</th>
<th>8000Hz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recommended noise criteria values (NC-27)</td>
<td>55</td>
<td>46</td>
<td>39</td>
<td>33</td>
<td>28</td>
<td>26</td>
<td>25</td>
<td>24</td>
</tr>
<tr>
<td>Design criteria: Excess noise to be mitigated</td>
<td>1</td>
<td>13</td>
<td>17</td>
<td>18</td>
<td>15</td>
<td>10</td>
<td>11</td>
<td>13</td>
</tr>
</tbody>
</table>

The measured data is evaluated according to established bands without regard to the characteristics of the offending sound (tonal, broadband, impulsive, etc.). An HVAC engineer would typically address the HVAC noise problem as presented by finding a suitable passive silencer that provides the quieting as needed.

2.1 Passive and active silencer technology

For the purposes of this discussion, we group HVAC silencers into the category of passive and active. In general, passive silencers provide acoustic attenuation in the following manner:

- No energy is added. Instead, existing fluidic energy is dissipated.
- Noise attenuation is achieved by introducing inefficiency in the flow.

In contrast, active silencers provide acoustic attenuation in the following manner:

- Energy is added to destructively interfere with the existing acoustic energy.
- Flow is either not – or minimally - affected.

2.2 Commercially-available passive HVAC silencers

Passive silencers can take on almost infinite geometry. They typically share the characteristic of introducing material surfaces into the flow. These surfaces affect the flow characteristics in a manner to reduce downstream noise. A representative commercially-available passive silencer – referred to as a Splitter-type Silencer – is shown in Figure 1.

Figure 1. Representative Passive Silencer (Lindab AB).

In terms of purchase-cost to noise reduction, passive silencers such as the example shown are high value. A hidden cost of a passive silencer is the expense of overcoming their flow impact.

2.2.1 Acoustic impact

The acoustic benefit provided by a passive silencer is presented in a manner very similar to that of the measured problem. This aids the HVAC engineer in identifying and applying a solution. Table 2 shows the band-wise dynamic insertion loss for a range of passive silencers at a face velocity of 2m/s.
### Table 2. Representative passive silencer reduction characteristics by model and spectral band.

<table>
<thead>
<tr>
<th>Model</th>
<th>63Hz</th>
<th>125Hz</th>
<th>250Hz</th>
<th>500Hz</th>
<th>1000Hz</th>
<th>2000Hz</th>
<th>4000Hz</th>
<th>8000Hz</th>
</tr>
</thead>
<tbody>
<tr>
<td>RXX/YYYY-600</td>
<td>5</td>
<td>13</td>
<td>18</td>
<td>26</td>
<td>43</td>
<td>48</td>
<td>46</td>
<td>42</td>
</tr>
<tr>
<td>RXX/YYYY-900</td>
<td>9</td>
<td>16</td>
<td>25</td>
<td>38</td>
<td>48</td>
<td>50</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>RXX/YYYY-1200</td>
<td>11</td>
<td>20</td>
<td>32</td>
<td>49</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>RXX/YYYY-1500</td>
<td>14</td>
<td>24</td>
<td>38</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>RXX/YYYY-1800</td>
<td>15</td>
<td>28</td>
<td>45</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>RXX/YYYY-2100</td>
<td>16</td>
<td>30</td>
<td>49</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>RXX/YYYY-2400</td>
<td>18</td>
<td>36</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>50</td>
</tr>
</tbody>
</table>

To solve an existing problem, the HVAC engineer need only choose a silencer whose dynamic insertion loss meets or exceeds what is needed for every band.

#### 2.2.2 Flow impact and true operating cost

The dynamic insertion loss shown above comes with a corresponding pressure drop. At 2m/s of face velocity, the passive silencers shown above have a pressure drop ranging from 45-55 Pa. To maintain downstream pressure, additional energy needs to be provided to the prime mover to overcome this pressure drop. So, while the passive HVAC silencer requires no power for operation, the air handler requires additional power to overcome it.

#### 2.3 Commercially-available active HVAC silencers

The active silencers that we will consider are made by the company of the authors, TechnoFirst. The two production models of active HVAC silencer manufactured by TechnoFirst are the ASCa™ and ActA™. The ASCa™ and ActA™ differ primarily by the fact that the ASCa™ is typically used as an out-of-flow device, while the ActA™ is an in-flow device sold under license with Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung e.V.

The ASCa™ and ActA™ are designed to be placed in configurations as required by a customer HVAC design. The basic version of the ASCa and its operating principle are shown in Figure 2. The ActA™ and its operating principle are shown in Figure 3.

![Figure 2. ASCa active HVAC silencer and operating principle (TechnoFirst SA).](image)

The devices use microphones to sense the problem acoustic condition. In addition to analog control, a DSP-based controller running a proprietary adaptive control algorithm can also be used to calculate a suitable cancellation sequence. A speaker delivers that sequence. Both devices can be configured for feedback and/or feedforward control based on customer requirements. Depending upon customer needs, additional passive treatment can be used in conjunction with the active units.
2.3.1 Acoustic impact

The acoustic performance of an active HVAC silencer varies with configuration. In some applications, the active silencer is installed with a robust control algorithm that provides broadband noise reduction. In other applications, an adaptive optimal control algorithm can provide tonal quieting.

Passive HVAC control is achieved by dissipating energy. Because active control work by adding energy – effectively without limitation – greater theoretical levels of reduction are possible. This is particularly the case for the low frequency region where active control is most effective. In applications where active control is unable to provide the high frequency reduction needed, lesser amounts of passive treatment can be added to provide only the high frequency reduction needed.

2.3.2 Flow impact and true operating cost

An active silencer requires power to function. The control unit with integrated amplifier consumes – on average – 8 watts.

This power requirement is more than offset by the lack of need to increase the power supplied to the air handler. The ASCa™ unit – as an out-of-flow device – does not add any measureable pressure drop. A typical ActA™ application shows a pressure drop of less then 10 Pa. This is a fraction of the pressure drop of a passive silencer.

2.4 The importance of tunability in HVAC control

The statement was made that “To solve an existing problem, the HVAC engineer need only choose a silencer whose dynamic insertion loss meet or exceeds what is needed for every band.” This statement highlights a problem caused by the fact that the band-wise dynamic insertion loss is not adjustable.

In the case presented in Section 2.0, our HVAC engineer desires a system providing the dynamic insertion loss defined in Table 1. Looking at Table 2, it appears that the RXX/YYY-600 model will provide the reduction required with the 125Hz band being the limiting factor. Two important points must be considered:

- The dynamic insertion loss provided by this choice exceeds the requirement in every other band making the solution inefficient in those spectral ranges.
- If the disturbance is tonal, the reductions – which are band-wise averages – may not be sufficient. This would mean that a solution with even greater pressure drop would be required.
3. An HVAC silencing case study

An installation was made on a 1500m$^3$/h dual AHU air handler that compared a splitter-type passive silencer and a TechnoFirst ActA™ active silencer with decreased passive treatment. The results can alternately be described as acoustic and financial.

3.1 Noise reduction

Figure 4 shows the following spectra: the original uncontrolled spectrum (4a); the spectrum resulting from the installation of a splitter-type passive HVAC silencer (4b); and the spectrum resulting from the installation of an ActA™ active HVAC silencer with a greatly reduced amount of passive treatment to provide needed high frequency noise reduction. The results obtained from the two control solutions were comparable – with the passive solution providing 10.5dB of reduction compared to the active+limited passive solution providing 16dB.

![Figure 4. Original uncontrolled (4a), passive (4b), and active (4c) spectra.](image)

3.2 Peripheral costs

The more important issue than noise reduction, though, is the resulting operational cost. Table 3 shows the operating comparison of the two control solutions.

<table>
<thead>
<tr>
<th></th>
<th>Q (m$^3$/h)</th>
<th>$\Delta P$ (Pa)</th>
<th>AHU Motor Speed (RPM)</th>
<th>Power consumption (kW @ 230V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Splitter-type passive HVAC silencer</td>
<td>1500</td>
<td>50</td>
<td>1500</td>
<td>1.34</td>
</tr>
<tr>
<td>ActA™ active HVAC silencer</td>
<td>1500</td>
<td>7</td>
<td>1000</td>
<td>0.54</td>
</tr>
</tbody>
</table>

Assuming an average cost of $0.15/kW – a conservative estimate – the energy efficiency of this single active HVAC silencing unit would save $1068 annually. For municipal and industrial application, the scale of the savings can be huge.

For the ASCa™ control solution, the savings can be even greater. As an out-of-flow device, there is virtually no pressure drop across the point of control.

4. Active quieting of internal combustion engines

An application of active quieting outside of HVAC control is the use of the TechnoFirst ExAct™ active exhaust system for the muffling of internal combustion engines. The ExAct™ works by modulating the flow of the high temperature exhaust gases. The modulation of a throttle plate – combined with the storage of energy in an upstream chamber – can result in a reduction of tonal noise when properly controlled. Figure 5 shows the ExAct™ device and a depiction of the principle of operation.
4.1 Engine backpressure and performance

Conventional passive baffled mufflers can have high backpressure when high levels of attenuation are required. Typically, an increase in backpressure means decreased engine performance.

The following points summarize the effect of backpressure on engine operation:

- Brake specific fuel consumption increases with increased backpressure to provide the extra power necessary to overcome the increased pumping losses while maintaining a constant brake power output.
- Exhaust gas temperature increases significantly with increasing back pressure due to the increased power required (to overcome the additional pumping work) and the reduced airflow.
- Imposed back pressure fluctuations cause large exhaust temperature fluctuations, which further increases the maximum temperature and also induces thermal cycling - leading to increased wear.

4.2 ExAct™ application performance

Because the ExAct™ operates with the controlling throttle plate only slightly off horizontal providing, the device provides low frequency tonal reduction with almost negligible back pressure. The static angle of the device can be set to the backpressure desired by the engine design.

Figure 6 shows the downstream pressure of an exhaust line with an ExAct™ providing tonal reductions. Also shown are tonal enhancements desired for sound quality concerns.
5. Conclusion

This paper considered the energy savings that could be obtained when using an active control solution for HVAC and internal combustion engine applications. In both cases, the savings result from the decreased pressure drop of the active control solution over the corresponding passive solution.

For HVAC control, an application was presented where a single silencing unit resulted in an approximate savings of $1068/year. For large facilities, the scalable savings can be significant. For internal combustion engine control, an active control device providing low frequency noise reduction with minimal backpressure can increase fuel economy and help maintain engine health.

In both domains, the use of active control results in decreased energy consumption. This should be viewed as an important consideration when considering the true cost and value of noise control solutions.

REFERENCES