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SEARCH FOR A SUITABLE RECTANGULAR ATTENUATOR

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ABSTRACT

The noise reduction in the ventilation system of buildings is the main challenge in every ventilation project. Silencers were created as the solution for this task. Therefore, Halton, a company that is the leader in indoor quality solutions, was interested in starting production of their attenuators in addition to other ventilation equipment.

The main aim of the thesis work is to find the silencer manufacturer that produces the best-performing product compared to other suppliers. Another aim is to get acquainted with the silencer's performance during laboratory tests. In the future, Halton intends to develop its attenuators based on the structure and performance of the selected silencers.

The work started by researching the literature sources using Kaakkuri e-library and answering the following questions: What is an attenuator? What are the main parameters that can help to determine an excellent silencer from an average one? What tests have to be conducted to obtain these parameters? After the theoretical part was finished and the needed information was collected, the practical part was begun. Two tests were performed, and a comparison between the collected data and the manufacturer's data was made.

The study showed that not all the companies wanted to connect for future cooperation. However, Alnor was selected as a potential silencer supplier despite some controversial points. The test results obtained in the laboratory sometimes were far from the values provided by the manufacturer.

Keywords: dissipative silencer, rectangular attenuator, pressure drop, insertion loss

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1 INTRODUCTION

The competent design of HVAC systems is essential for the occupant's health and well-being. High noise levels, inadequate humidity, and temperature levels are major components of a sick building syndrome, and ventilation silencers have a direct impact on these values. Unfortunately, Halton, which is a major Finnish ventilation system supplier, does not have its production of silencers. Making its product or buying it from other companies will provide Halton engineers with the ability to design their equipment more precisely, ensuring higher air quality for the whole ventilation system.

Halton is a family-owned Finnish company founded in 1969 by Seppo Halttunen. Most of the company's sales were connected to store furniture, but soon, the company's focus shifted. In 1984, the Halttunen family took a significant risk and established the Halton Innovation Club in Kausala /1/. The noticeable thing is that all simulations made for this thesis were performed in this exact centre, which defined Halton as an HVAC company.

Nowadays, Halton is one of the world leaders in indoor quality solutions, with a yearly turnover of 270 million euros /1/. It manufactures equipment for commercial and public buildings, laboratories and healthcare institutions, professional kitchens and restaurants, energy production and heavy industry environments, and even marine vessels. It also has a presence in 35 countries with around 1900 workers and engineers.

2 AIMS

The aim of this thesis is to find suitable silencers, catalogue them, and integrate them into Halton's systems. This thesis also aims to make a comparison between different suppliers worldwide. The main comparison attributes will be case material, absorption, sound level, and pressure loss. The product will be integrated into Halton's database after all necessary attributes are tested, even if they are provided by the supplier. These products will be tested by creating a test plant inside Halton's laboratory and measuring specific values necessary for assessing silencers' performance. The process of creating the test plant will be described in this thesis work, as well as the theory behind it. At the end of the thesis, an analysis of the received data will be performed to determine the most suitable silencer for Halton.

This project will also describe what factors can affect silencers' performance. It also aims to describe step-by-step measuring procedures of silencers, which will help future engineers in their work.

3 THEORETICAL OVERVIEW

For more than a century, aerodynamic properties have been researched globally. Knowing these parameters is essential in designing adequate ventilation systems /1/. These properties are usually calculated in specific laboratories, which Halton has. For a better understanding of the future measuring process, it is necessary to know the theory behind the work process of silencers. This is why, in this chapter, the main physical parameters that influence the behaviour of HVAC silencers and their working principles and role in HVAC systems are described.

3.1 Noise sources in ventilation systems

In ventilation systems, noise is produced by moving air jets and vibrating surfaces. Sound wattage power is low, but the human ear's sensitivity makes it sufficient to cause discontent among building tenants. The most common noise sources in building HVAC systems are fans, duct components, grilles, diffusers, plants (such as chillers, boilers, compressors, cooling towers, condensers, and pumps /2/. An important thing to consider is that all HVAC equipment and parts have different sound frequencies, as demonstrated in Figure 1. This topic becomes significant when choosing the type of silencer, as some types are better suitable for specific frequencies or are tuned to particular frequencies.

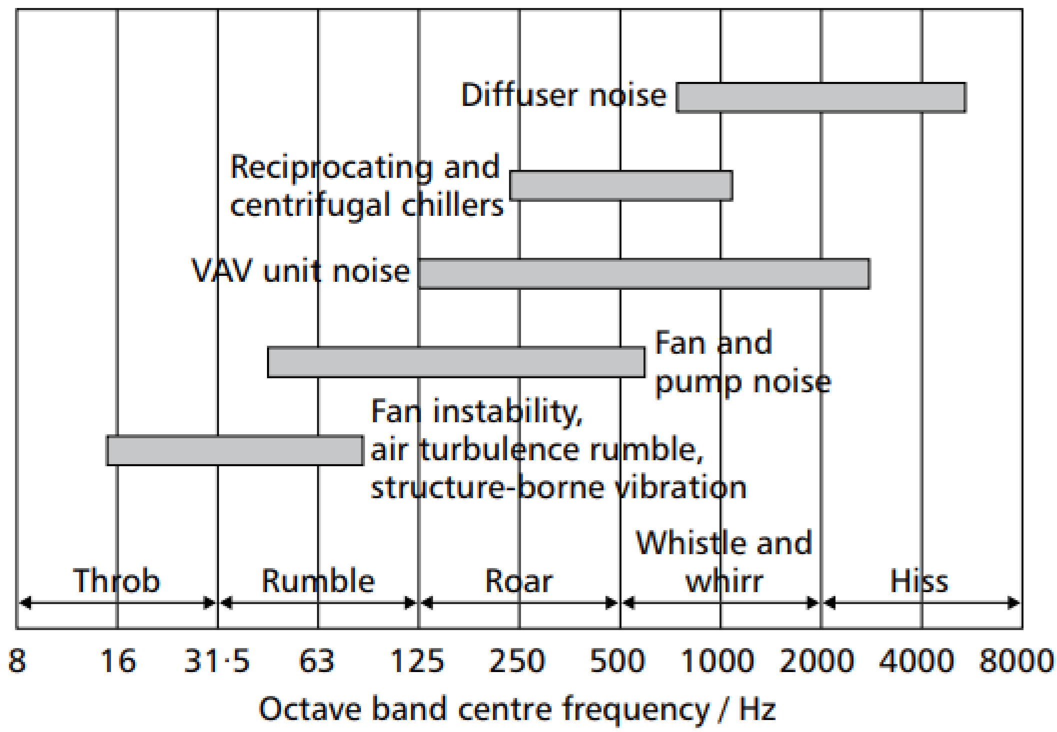


Figure 1. Typical frequencies of HVAC components /3, p. 4/

As Figure 1 indicates, noise emanating from the central plant, including fans and pumps, typically extends up to approximately 500 Hz. Variable air volume (VAV) units introduce noise spanning the range of 125 to 3000 Hz, with fan-powered units contributing predominantly to the lower end of this spectrum. Chillers generate noise from 250 to 1000 Hz, while higher frequencies are expected to diffuse noise. The lowest frequencies observed are typically a consequence of improperly executed installations /3/.

3.2 Silencers theoretical overview

Silencers, also called absorbers or sound attenuators, are utilities made to reduce the volume of sound and noise by reducing the sound pressure by using different methods. These methods generally include porous insulating material, expansion chambers, or intertwined perforated pipes. Silencers are usually installed on a fan's intake or discharge side or at the receiver side of other noise generators, such as dampers, terminal boxes, or valves. /2/

Dissipative silencers – this category of silencers uses sound-absorbing material to reduce the sound level. This material is usually fiberglass or mineral wool. However, mineral wool is hindered by its contamination risk in high-temperature applications due to erosion, even when the material is protected by a perforated metal. The erosion of the sound-absorbing material can be further reduced by combining a perforated metal layer with a polymer film liner or fiberglass cloth. Dissipative silencers with this combined protection are primarily used in facilities where air quality is a matter of significant importance, such as hospitals, clean rooms, or laboratories. The performance of dissipative silencers depends primarily on the silencer's length, density, and type of absorption material and the thickness, number, and shape of splitters or center bodies. /2/

Reactive silencer – this type of silencer looks similar to the dissipative silencers, but it is constructed using only metal parts – both perforated and non-perforated. The working principle of reactive silencers is based on the resonation effect. It is achieved by creating small chambers of specific shapes and sizes behind perforated metal, which interacts with the airflow to reduce the sound level at particular frequencies. Compared to dissipative silencers, the disadvantage of this type of silencer is the need to tune the chambers. The chambers are adjusted to specific frequencies in advance, and the silencer's performance on frequencies outside this premade range is severely hampered. /2/

Active silencer – the main working principle of an active silencer differs drastically from dissipative or reactive silencers and is based on the production of opposite soundwaves. This is why this kind of silencer is also called a noise-cancelling system. The system uses an internal microphone that measures the amplitude and frequency of a sound and gives a signal to an external device. The external device converts the digital signal to sound waves, which intervene with the primary source. The system also has an error microphone, which provides the feedback needed to adjust the amplitude and frequency of the opposite sound. The advantages of the active silencers are a low-pressure drop because almost all components are mounted at the external side of a duct and the self-regulation ability. The main disadvantage is poor performance on mid and high frequencies. This is why components of passive silencers are often combined with active silencers to achieve the best performance on all frequency ranges. /2/

The comparison of different silencers is based mainly on parameters such as insertion loss, dynamic insertion loss, airflow-generated noise, and pressure drop. These values are calculated based on the test results made under ideal conditions. The overall principle of the test plant used in Halton during this research can be observed in Figure 2 below.

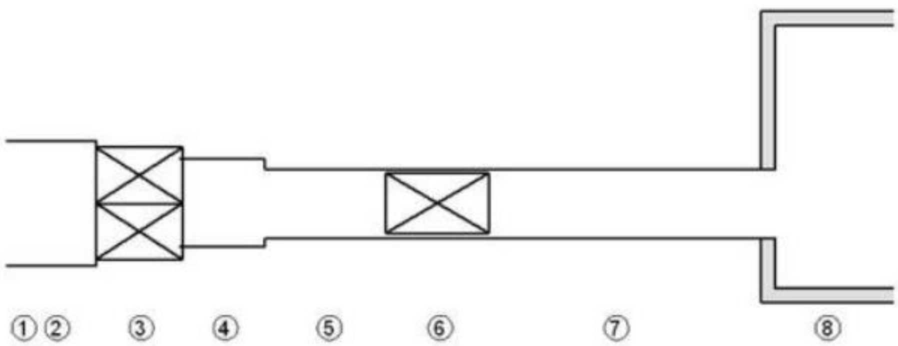


Figure 2. Test plant for Rating Straight Duct Silencers with or Without Airflow /3, p. 62/

1. Airflow measurement station
2. System fan
3. System silencer
4. Signal source chamber
5. Pressure test station
6. Straight silencer under test
7. Pressure test station
8. Reverberation room

As Figure 2 indicates, the flow goes from left to right through the airflow measurement system, the fan, and the signal source chamber, which creates a noise of the desired pressure level and frequency. A system silencer is installed to avoid measurement errors due to the fan noise overlapping with signal noise. Two pressure meters are required to measure air pressure before and after a silencer.

Insertion loss depicts the noise level reduction in a duct system after installing the silencer. This value is measured without airflow, usually by creating noise from a loudspeaker /2, p. 40/ and published in full octave bands ranging from 63 to 8000 Hz.

Dynamic insertion loss, on the other hand, shows the noise level from a specific airflow direction and velocity. It is different for forward and reverse flow with respect to the direction of noise propagation. Insertion loss and dynamic insertion loss of various types of silencers can vary significantly depending on the sound frequency. This difference can be observed in Figure 3, where the performance of a dissipative and reactive silencer is compared.

Pressure drop shows the difference between available airflow pressure before and after the silencer. Airflow-generated noise is the minimal noise level that can be achieved by this specific silencer and depends on the silencer's form factor.

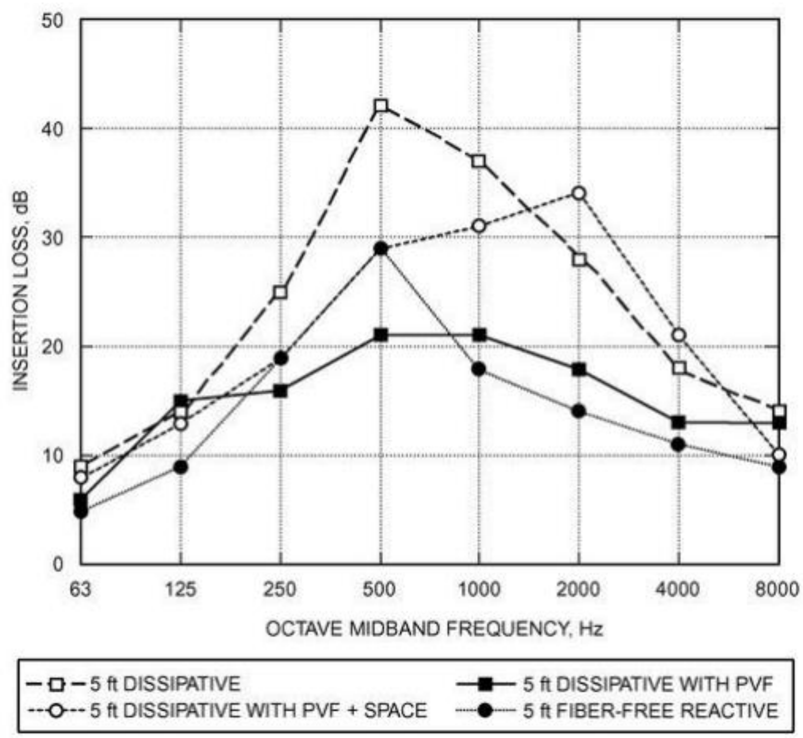


Figure 3. Comparison of a similar length Dissipative and Reactive Silencer /3, p. 63/

As Figure 3 shows, the performance of reactive silencers on low frequencies is comparable with a dissipative silencer. However, the difference in mid-frequencies is significant. A reactive silencer usually requires a longer length to achieve the same performance as a dissipative one.

3.3 Noise legislation in Finland

The legislation considering noise levels in new buildings in Finland is based on the Decree of the Ministry of the Environment on the Acoustic Environment of Buildings /4/. This Decree lays down provisions on sound insulation, noise and vibration reduction, and acoustic conditions of buildings and provides required sound level values for designers. These values can be observed in Table 1 below. The Decree also states that no alterations or repairs should weaken the sound insulation and sound pressure level of the building.

Table 1. Required design sound level for different spaces /4, p.3/.

Room and outdoor space	Continuous broadband noise		Impulsive or narrowband noise	
	A-weighted equivalent continuous sound level ($L_{Aeq,T}$), in dB	Maximum sound pressure level ($L_{AFmax,T}$), in dB	A-weighted equivalent continuous sound level ($L_{Aeq,T}$), in dB	Maximum sound pressure level ($L_{AFmax,T}$), in dB
Residential room or accommodation or patient room	28	33	25	30
Residential kitchen or recreational room in a building	33	38	30	35
Staircase or exit route	38	43	35	40
Outdoor space	45	50	40	45

It can be noticed in Table 1 that the sound level of impulsive noise is lower than that of continuous noise. This is explained by the fact that the human ear is much more sensitive to sudden sound level change and can be more noticeable even if the sound pressure is lower. A-weighted equivalent continuous sound level is the level of non-temporary noise in a room or outdoor space.

4 METHODS

During the literature research, the main task was to get acquainted with silencers' work processes and main characteristics. The theoretical overview included a search and observation of articles, books, and other sources that included information related to the investigated topic. Kaakkuri online library has been used as a primary source of the literature.

The practical part began with searching rectangular silencer manufacturers on Google's website. Unexpectedly, there were not plenty of manufacturers producing rectangular silencers around the whole of Europe. Only eight companies were chosen because they had rectangular attenuators in their product lists, which enabled conducting an e-mail interview for further investigation of their products. Another three companies were added due to colleagues' recommendations during a Microsoft Teams call. These companies had previously interacted with Halton and their products were already well-known by my colleagues.

4.1 An e-mail interview

An e-mail interview was chosen as one of the research methods of this thesis. The advantages of using this kind of communication were the range of participants: we were able to interview company representatives from all around the world and the possibility to conduct several interviews simultaneously, which allowed spending less time collecting all the data. To conduct a good e-mail interview, firstly, a protocol shall be developed: participants shall be selected, the main questions have to be chosen, and time limits for an interview shall be set /5, 1418/. If participants were selected during a Google search, then the main questions were specified by Halton’s research and development specialist. Halton's preferences for a perfect supplier were a wide range of rectangular silencer dimensions, markets in central Europe and Scandinavia for the fastest delivery around the world, MagiCAD and Revit product drawings, and finally, all sound tests had been run, and the data had been provided. Thereafter, the next interview questions were created:

- What is the size range of the rectangular silencer that you have been producing?
- From what country can you dispatch your products?
- Do you have MagiCAD and Revit product drawings?
- Have you made sound measurement tests? Do you have the test data for all ranges of the silencers or only for a few samples?

The time limit for one month of silence was selected from the last e-mail sent from Halton.

4.2 Equipment inside the reverberation room

One possible way to conduct sound measurements is using a reverberation room. The chamber's purpose is to diffuse acoustic waves so that acoustic energy flows in all directions. Therefore, the reverberation room is designed to reflect sound from all surfaces. Also, the sound measurement room shall be well isolated from extraneous sounds in order to avoid incorrect results due to the presence of background noise (Figure 4).

Figure 4. Entrance into the reverberation room on the pneumatic bellows

As shown in Figure 4, Halton perfectly coped with the isolation task by installing the reverberation room on pneumatic bellows and choosing hard concrete as the wall material. The main parameters of the room were measured using a laser ruler. The values were a length of 7.361m, a width of 5.855m, and a height of 4.636m. The reverberation room has a space volume of 200m^3 and an absorption area of around 209 m^2.

The end of the ductwork is equipped with a transmission element with an opening angle of 15º. The transmission element is needed to compensate for sound reflection into the ductwork. The airflow from the transmission element should not reach any objects within one meter.

The most sensitive sound measurement part is a microphone that can be easily damaged even due to air temperature or pressure changes. Because of that, to obtain accurate sound data, the microphone had to be calibrated before the measurements. Therefore, an easy-to-use sound calibrator, Rion NC-74, is used (Figure 5).

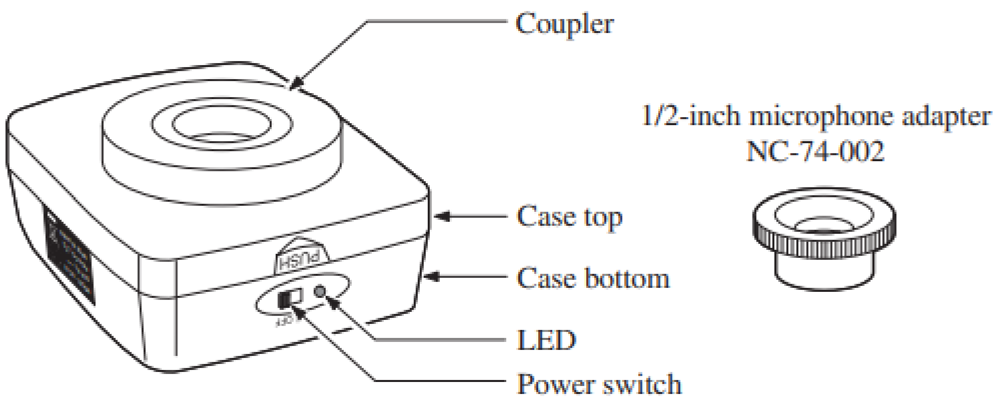


Figure 5. A sound calibrator Rion NC-74 /6/

The microphone is connected to the switched-off calibrator through a coupler, as demonstrated in Figure 5. After adjusting the sound level meter range so that 94 dB could be measured, the calibrator was turned on, and the sound level meter was corrected to demonstrate 94 dB /6/. After all these steps, the calibration process may be considered as finished.

The microphone, which had to be calibrated, is GRAS 40HL, a low-noise microphone used to measure sound pressure levels within the human hearing range. The device complies with ISO standards 3741 and 7235. Frequencies ranging from 10Hz to 16kHz and dynamic range from 6.5 dB to 110dB may be measured by the sensitive microphone /7/. A two-channel real-time 1/3 octave analyzer, Nor121, was used to collect and process the data. The analyzer is lightweight with a 120dB dynamic range /8/.

During the measurements, the microphone was fastened to a rotating boom Nor265. The main purpose of the stand device was to obtain measurement data by moving the microphone back and forth. But in order to rotate the microphone circularly, not straight, a pivoted arm was added to the rotating boom (Figure 6).

Figure 6. Rotating boom Nor265 and the pivoted arm

The placement of the rotating microphone stand inside Halton's reverberation room is demonstrated in Figure 6. The boom is fastened to the wall, while the microphone must be at the pivoted arm's end. Also, the room is equipped with loudspeakers for pink noise creation to measure reverberation time. However, loudspeakers in the reverberation room have not been used in the thesis measurements.

The sound measurement results can be affected by the air condition different from the standard. Therefore, this information shall be checked before measurements. A micromanometer, barometer, hygrometer, and thermometer were used to collect air condition data (Figure 7).

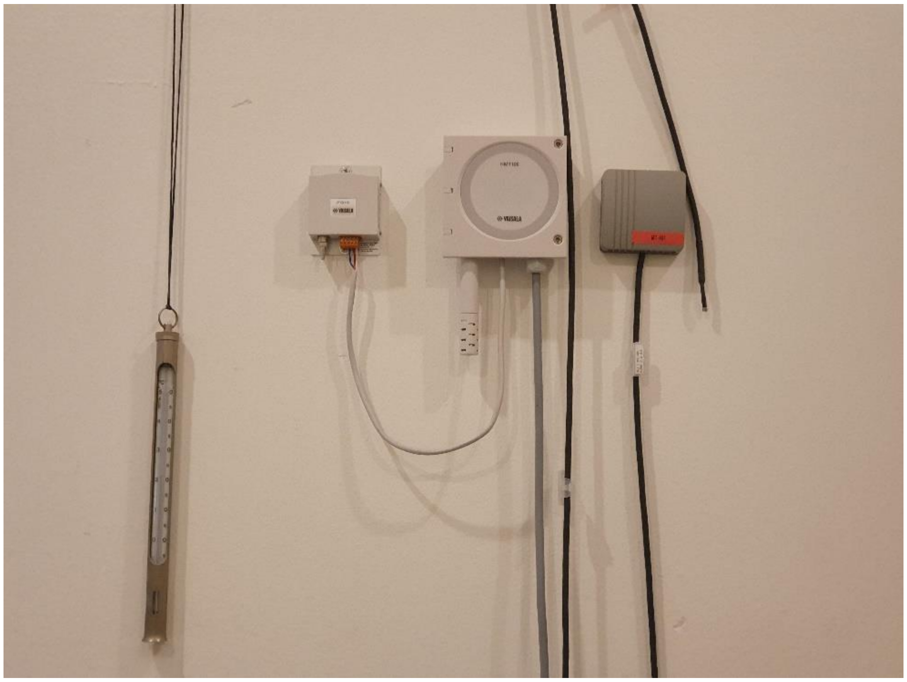


Figure 7. Left to right: micromanometer, barometer, hygrometer, and thermometer

All the instruments are attached to the reverberation room's wall, as demonstrated in Figure 7. Data from all the devices besides the micromanometer goes directly to the computer. The micromanometer is used to follow the air pressure, the barometer - to check air pressure, the hygrometer - to know air humidity, and the thermometer - to follow the air temperature.

As a result, all the tool information is summarized in Table 2 with serial numbers and calibration dates.

Table 2. Instruments inside the reverberation room for sound measurements

Instrument	Type code	Serial number	Calibration date
Sound calibrator	Rion NC-74	34336052	1 June 2022
Microphone	GRAS 40HL	139663	8 July 2021
Real-time analyzer	Norsonic 121	31426	7 June 2021
Rotating boom	Nor 265	29292	
Micromanometer	DPM RS232		14 February 2022
Barometer	VAISALA PTB110	F2050002	
Hygrometer	VAISALA HMT100	F2110042	
Thermometer	MT-401		

4.3 Equipment outside of the reverberation room

Commonly, the attenuator measurement starts from the fan. The fan shall be isolated from vibrations and speed adjustable to accomplish various flow rates. All equipment is joined with test ducts. To provide accurate measurements, the test ducts shall be straight and equal in cross sections, preferably with the exact dimensions of the test object.

At first, airflow from the fan goes through a primary silencer to attenuate the noise that the fan is producing. After that, Halton's laboratory has three selectable measurement ducts with interchangeable orifice plates for air flow rate measurement. In Figure 8, the following stage begins with a secondary attenuator, which is efficient at all frequencies and includes a sound source chamber for insertion loss measurement.

Figure 8. Installation for tests of a rectangular silencer

Figure 8 demonstrates that after the attenuator, the ductwork is changed to the correct size and shape of the measured sound attenuator – in this case, the silencer is rectangular. Further, the airflow goes either through the substitution duct or the examined product. The substitution duct has to have the same shape and dimension as the sound attenuator. If the attenuator is rectangular, the test duct must be changed to a round duct before it goes to the sound measurement room. The transmission element that connects the test object or substitution duct with the reverberation room should be designed to suppress pronounced resonances behind the test object, and absorption should not occur into the duct (Figure 9).

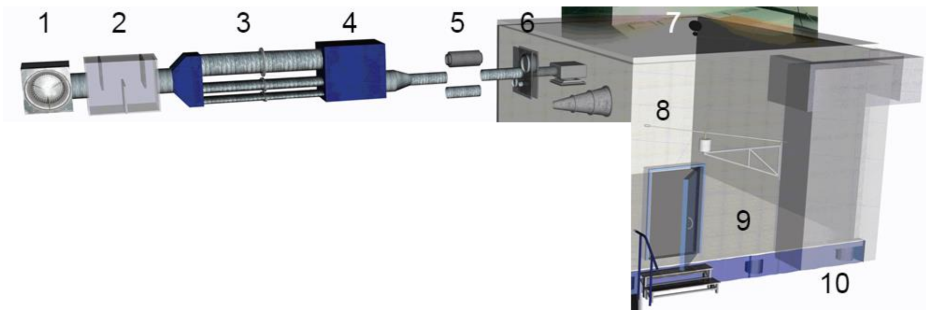


Figure 9. General test installation model:

1. Medium-pressure fan with rotation speed control
2. Primary sound attenuator
3. Selectable measurement ducts with interchangeable orifice plates for air flow rate measurement
4. Secondary sound attenuator
5. Substitution duct or product to be examined
6. Transmission element
7. Loudspeakers
8. Microphone
9. Reverberation room
10. Pneumatic bellows

4.4 Sound measurement process

In order to achieve the goal of the thesis project and, more specifically, to compare attenuators from different manufacturers, two parameters were chosen: a dynamic insertion loss and a pressure drop. Sound pressure level reduction expected when an attenuator is installed in the ductwork is known as a dynamic insertion loss. Since the main purpose of a silencer is to decrease noise level, the first parameter is the most crucial in the silencer selection process. Commonly, the data is provided for the range from 63Hz to 8000Hz at varying air flows. The second value is helpful to demonstrate static pressure changes in the attenuator: a high-pressure drop may cause an inefficient operation of the whole system.

Therefore, the value should preferably be below 87 Pa /9/. Then, two tests using a reverberation room were conducted to determine the necessary parameters.

4.5 Pressure drop measurement

The pressure drop measurement test consists of two measurement parts. For the first part, the experimental setup for our measurements consists of a fan, primary attenuator, selectable measurement duct, secondary attenuator, rectangular ductwork, examined rectangular silencer, and round ductwork before the sound measurement room. A calibrated manometer is used to measure pressure in the duct. The examined rectangular silencer was replaced by the same dimension substitution duct for the second part, as Figure 10 demonstrates.

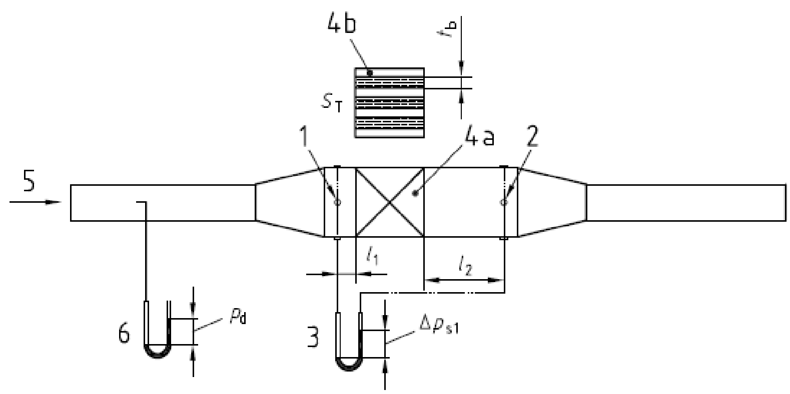


Figure 10. Test set-up for the measurements of total pressure loss /10, p.16/:

1. Upstream static pressure measurement
2. Downstream static pressure measurement
3. Manometer

4a. Substitution duct
4b. Measured silencer
5. Direction of flow
6. Flow rate measurements

The static pressure measurement devices shall be installed with duct diameters from 2.5 to 5 for upstream and downstream airflow in order to avoid turbulence areas near the silencer in Figure 10. Two test series have to be carried out: one with the measured silencer and another with the substitution duct that replaced the test object. The test series were run four times at different airflows.

<u>Measurement steps based on ISO 7235:2003:</u>

- Insert product info into the measurement program.
- Carry out sound development measurements at 25 dB, 30 dB, 35 dB, and 40 dB. Adjust the airflow to meet the correct sound level.
- Write down the air volumes used for each sound level.
- Replace the sound attenuator with the substitution duct.
- Measure the same airflows with the substitution duct.

4.6 Insertion loss measurement

As in the first test, two measurement parts are needed to measure the insertion loss. For the first part, the proper installation sequence is a secondary attenuator with a sound source, rectangular ductwork, substitution duct, and round ductwork before the sound measurement room; for the second part, the substitution duct was replaced by the examined rectangular silencer. Microphone position, flow condition, and duct sizes shall be constant during both test series. Both measurements are carried out without air.

Measurement steps based on ISO 7235:2003:

- Insert product info into the measurement program.
- Start the sound source and adjust the sound level from equaliser to 60 dB equally for every frequency band.
- Measure the sound level from the room with the substitution duct.
- Replace the substitution duct with the sound attenuator.
- Keep the same sound level on the equaliser.
- Measure the sound level from the room with a sound attenuator.

The insertion loss is calculated by subtracting the sound pressure level measured when the attenuator was installed from the data when the attenuator was replaced by the substitution duct /11, p.3/. Despite the obtained result being in a one-third octave band, using formula 1 /10/, it may be easily converted into a one-octave band:

$$D_{1/1} = -10 \cdot \lg\left(\frac{1}{3}\sum_{k=1}^{3} 10^{-0,1D_{1/3,k}}\right), \quad (1)$$

where,

$D_{1/3,k}$ – the attenuation values for the three one-third-octave bands.

4.7 Comparison

At the comparison stage, the products were reviewed and compared using parameters defined in manufacturers' technical brochures and during tests. Overall dimensions such as width, height, length, weight, baffle thickness, and gap were chosen to make a comparison between parameters obtained from AlnorSILENT software and results from size and weight measurements using a ruler and scales. After that, pressure drop and insertion loss were determined by two tests in Halton's laboratory and were compared to the values from the technical brochure.

According to Halton's sales, the most widespread dimensions of a rectangular silencer were 300x300x1200 and 600x600x1200. Therefore, these two samples were selected to be ordered and tested in the laboratory for further investigation. Because of the long silencer's order name, it was decided to simplify the designations to the signs in the table below. Short names were used throughout the thesis.

Table 3. Correlation between order name and short name of silencers

Whole name	Short name
SLC-100-02-0300-0300-0600	SLC-300
SLC-100-04-0600-0300-1000	SLC-600

5 RESULTS

In this chapter, the results of the whole work were assembled. Due to a lot of data being gathered during the thesis, it was necessary to divide the chapter into subchapters for a better understanding of the work done. The first data that was obtained was a result of an e-mail interview. Afterwards, based on this result, silencers were ordered, and two tests were conducted, which led to the creation of two more subchapters: pressure drop test and insertion loss test.

5.1 An e-mail interview

During communication, an observation emerged that, on one hand, some manufacturers were not interested in cooperation with Halton at all; on the other hand, unfortunately, other companies had other significant disadvantages. The result of the first part of the research has been structured into Table 4. The order of manufacturers in the table is by the discovery date: from the first found to the most recent.

Table 4. Pros and cons of different suppliers

Name	Advantages	Disadvantages
AirGroup	+ As a reference point of view for prices and availability + Send a rectangular silencer	- Located in Finland - Sound measurements are done only for round connection silencers
Alnor	+ Have a selection program where all test information is provided for the whole range of silencers + Expanded PVC as a possible insulation material + Can design Revit models if needed	- The smallest size is 200mm, not 150mm - Does not have MagiCAD and Revit models for rectangular silencers .
Swegon		- The competitor
Goveco	+ Good communication	- Sell products only out of Europe
FanTech		- The competitor - Located in the UK
Acoustics		- Located in Norway - Products with a thick core
EcoClima	+ Good communication	- Expensive product
TroxTechnik		- The competitor
IacAcoustic		- The competitor - Located in the UK
BARCOL- AIR		- The competitor
Lindab		- The competitor

The dimensions of the ordered samples were chosen after the introduction to Halton's sales report for the year 2022. The most popular equipment sizes for rectangular ducts were widths 300mm and 600mm with lengths of 600mm and 1000mm.

Firstly, the silencers' main dimensions, such as width, height, length, weight, baffle thickness, and the gap between baffles for rectangular silencers, were collected from AlnorSILENT software. Secondly, these dimensions were measured by a ruler and a scale from all arrived attenuators. AlnorSILENT software was used to obtain pressure drop and insertion loss data. At the beginning, silencer dimensions and airflow were added to the program. After that, the needed information was calculated and recorded into a PDF file. Appendix 1 demonstrates how the final data was displayed in the program for a rectangular silencer SLC-300.

5.2 Pressure prop test

Test results were combined into an informative form in Tables 5 and 6 for easy understanding and analysis. The silencer's pressure drop and k-factor were calculated based on the available data.

Table 5. Pressure drop test result of SLC-300

I D	Flange size	Main Pressure	Airflow	Airflow	The sound level from the attenuator	Pressure drop	Duct pressure drop	Silencer's pressure drop	K factor
		P	q_v	q_v		Δp	Δp_{pipe}	$\Delta p_{silencer}$	k
		Pa	dm^3/s	m^3/h	dB(A)	Pa	Pa	Pa	
1	165/120	211	152.8	550.1	25.4	24.2	0.0	24.2	111.82
2	165/120	324	188.6	679.0	30.5	37.0	0.3	36.7	112.08
3	165/120	492	231.9	834.8	35.4	56.0	0.6	55.4	112.16
4	165/120	758	287.3	1034.3	40.4	85.8	0.8	85.0	112.18

Table 6. Pressure drop test result of SLC-600

I D	Flange size	Main Pressure	Airflow	Airflow	The sound level from the attenuator	Pressure drop	Duct pressure drop	Silencer's pressure drop	K factor
		P	q_v	q_v		Δp	Δp_{pipe}	$\Delta p_{silencer}$	k
		Pa	dm^3/s	m^3/h	dB(A)	Pa	Pa	Pa	
5	400/200	107.0	266.8	960.5	25.0	20.7	0.2	20.5	212.13
6	400/200	155.0	320.4	1153.4	30.4	29.1	0.3	28.8	214.93
7	400/200	223.0	384.9	1385.6	35.3	40.7	0.4	40.3	218.27
8	400/200	338.0	472.0	1699.2	40.2	60.4	0.6	59.8	219.73

Duct pressure drop (column 8, tables 5, 6) was obtained during the test with substitution duct, while pressure drop (column 7, tables 5, 6) was received from the test where the attenuator was installed. The silencer's pressure drop (column 9, tables 5, 6) was calculated by subtracting the duct pressure drop from the combined pressure drop.

5.3 Insertion loss test

Two test runs were measured for insertion loss parameters: the first was with the evaluated product, and the second was with the substitution duct. The attenuation results for a test conducted with the silencer were recorded in column 2 of Table 7. Conversely, the attenuation results obtained from tests employing the substitution duct were collected in column 3 of the same table. The data was captured in a one-third-octave band spanning the frequency range from 50Hz to 10000Hz. The insertion loss in a one-octave band (column 4) was calculated by subtraction the test data without an attenuator (column 3) from the test data with a silencer (column 2). Moreover, to make a comparison between the obtained results and the data from AlnorSILENT software, the data has been converted from the one-third-octave band to a one-octave band. This conversion was accomplished using Formula 1, as specified in the methodology, and the results are displayed in column 5 of the table below.

Table 7. Insertion loss test result for SLC-300 and SLC-600

f [Hz]	LpII [dB]	LpI [dB]	$D_{1/3}$ [dB]	$D_{1/1}$ [dB]
SLC-300				
50	37.8	32.4	5.4	
63	40.5	34.5	6	2.2
80	38.7	39.8	-1.1	
100	46.5	44.4	2.1	
125	50	45.3	4.7	3.5
160	51	46.9	4.1	
200	53.8	45.7	8.1	
250	53.4	43.6	9.8	9.8
315	52.2	39.6	12.6	
400	51.6	35.7	15.9	
500	50.9	32.8	18.1	18.4
630	51.9	26	25.9	
800	51.1	17	34.1	
1000	48	8.3	39.7	37.1
1250	48.6	7.9	40.7	
1600	48.1	8.8	39.3	
2000	51	11.8	39.2	38.8
2500	51	12.9	38.1	
3150	48.5	17.3	31.2	
4000	45	20	25	26.6
5000	48.7	23	25.7	
6300	45.2	22.7	22.5	
8000	42.7	22.3	20.4	21.1
10000	37.7	17	20.7	
SLC-600				
50	36.7	30.3	6.4	
63	49.7	38.2	11.5	9.2
80	52.1	40	12.1	
100	50.1	40.4	9.7	
125	49.7	41.3	8.4	7.6
160	50.7	45.1	5.6	
200	52.7	42.4	10.3	
250	51.7	36.9	14.8	13.4
315	51.8	31.8	20	
400	51	29.1	21.9	
500	49.9	23.1	26.8	25.4
630	50.9	13.7	37.2	
800	49.1	8.9	40.2	
1000	47.9	5.8	42.1	41.4
1250	49	6.7	42.3	
1600	48.1	7.2	40.9	

2000	50.3	9	41.3	41.1
2500	49.8	8.8	41	
3150	48	9.1	38.9	
4000	45.8	14.4	31.4	34.2
5000	48.9	13.6	35.3	
6300	45.3	13.8	31.5	
8000	44	17.1	26.9	27.1
10000	39	13.9	25.1	

The insertion loss started increasing from 50Hz and has reached its maximum point at 1000Hz and 2000Hz, as demonstrated in the Table above. This conclusion is true for both samples. However, due to its size and length, the SLC-600 shows better attenuation results than the smaller SLC-300.

6 ANALYSIS

Table 4 demonstrates that the most significant disadvantage is that a significant portion of the potential suppliers are direct competitors to Halton: 6 manufacturers out of 11. Another notable disadvantage was the geographical location of the manufacturers. Preference was given to suppliers with central European factories to ensure shipping and logistical efficiency. Therefore, another two companies were removed from view. Unexpectedly, Goveco initially considered a potential partner but was excluded from further consideration due to their policy of shipping products only outside of Europe, a discovery that was made after several months of communication with the company. Furthermore, in order to economize, it was decided to proceed without EcoClima, as their pricing structure was found to be significantly higher compared to other manufacturers under review. Ultimately, Alnor was the only supplier who answered all the questions and whose products' characteristics were evident. Alnor emerged as the most viable option, demonstrating a proactive approach answering all the questions and providing transparent information regarding its product specifications. To validate the accuracy of the manufacturer data, Halton proceeded to order two rectangular samples for testing within their laboratory facilities.

After size and weight measurements were done, the comparison Table 8 was created to compare the parameters of the evaluated products and their manufacturer descriptions. Error percentages were then calculated to highlight any disparities between the values. Any percentages exceeding 10% were marked in red, indicating significant deviations.

Table 8. Basic information comparison for rectangular silencers

		SLC-300			SLC-600		
Data from		Alnor	Halton	%	Alnor	Halton	%
Width	mm	300	303	1.0	600	599	-0.2
Height	mm	300	299	-0.3	300	304	1.3
Length	mm	600	600	0.0	1000	998	-0.2
Weight	kg	7.7	9.7	20.6	23.6	25.1	6.0
Baffle thickness	mm	100	102	2.0	100	103	2.9
Gap	mm	50	47.5	-5.3	67	46	-45.7

As Table 8 demonstrates, weight was the main difference between the technical specifications and the actual measurements of the ordered product. Notably, there is a two-kilogram variance observed in both samples. Furthermore, the narrower gap between baffles in the SLC-600 model raises concerns regarding its potential impact on performance during future tests. Despite these deviations, these parameters were not vital for Halton as long as performance was responded to the data provided in technical information.

In addition to size and weight measurements, a comprehensive comparison of pressure loss data obtained from AlnorSILENT with the measured values is presented in the tables below. Four test runs for each sample were made at 25 dB, 30 dB, 35 dB, and 40 dB noise levels. Also, the error percentages were calculated, recorded, and any deviations exceeding 10% were visually highlighted in red within Tables 9 and 10.

Table 9. Comparison between Alnor's and Halton's pressure losses for SLC-300

	SLC-300		
Airflow	Alnor	Halton	
m3/h	Pa	Pa	%
550	9	24.2	62.8
679	13	36.7	64.6
835	20	55.4	63.9
1034	30	85.0	64.7

Table 10. Comparison between Alnor's and Halton's pressure losses for SLC-600

	SLC-600		
Airflow	Alnor	Halton	
m3/h	Pa	Pa	%
961	9	20.5	56.1
1153	14	28.8	51.4
1386	20	40.3	50.4
1699	30	59.8	49.8

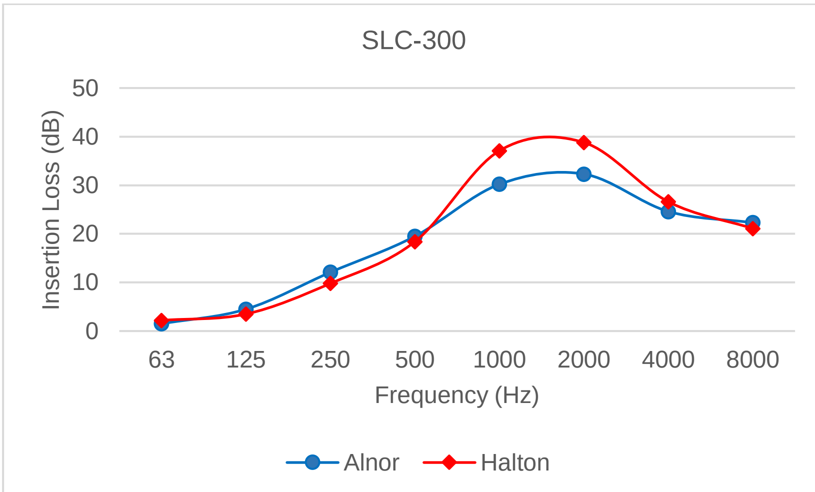
As we can see from the tables above, the pressure losses in the SLC-300 are almost triple, and in the SLC-600 twice as high as the information mentioned by the manufacturer. Unfortunately, the reason that caused this is unknown; the question and the results were sent to Alnor for future investigation. However, the assumption may be that the difference between the technical data and sample gaps can cause an error. Presumably, if the samples' baffles had been produced correctly in size, the pressure loss would have been less and closer to the software result.

After converting a one-third octave band into a one-octave band, Table 11 was created to collect and compare information from Alnor's technical brochure and Halton's test results. The columns capture information by frequency range, and the rows contain data from Alnor and Halton.

Table 11. Comparison between Alnor's and Halton's insertion loss for SCL-300 and SLC-600

		63Hz	125Hz	250Hz	500Hz	1000Hz	2000Hz	4000Hz	8000Hz
SLC-300	Alnor	1.5	4.5	12.1	19.5	30.2	32.3	24.6	22.3
	Halton	2.2	3.5	9.8	18.4	37.1	38.8	26.6	21.1
SLC-600	Alnor	1.9	5.1	15.9	24.3	33.7	33.6	26.1	24.1
	Halton	9.2	7.6	13.4	25.4	41.4	41.1	34.2	27.1

For clarity, the data from Table 11 was assembled into two charts below: the first was for SLC-300, and the second was for SLC-600. On a vertical scale, insertion loss was placed on a horizontal frequency range. Information from Alnor was designated in blue, while Halton's test result was marked in red.



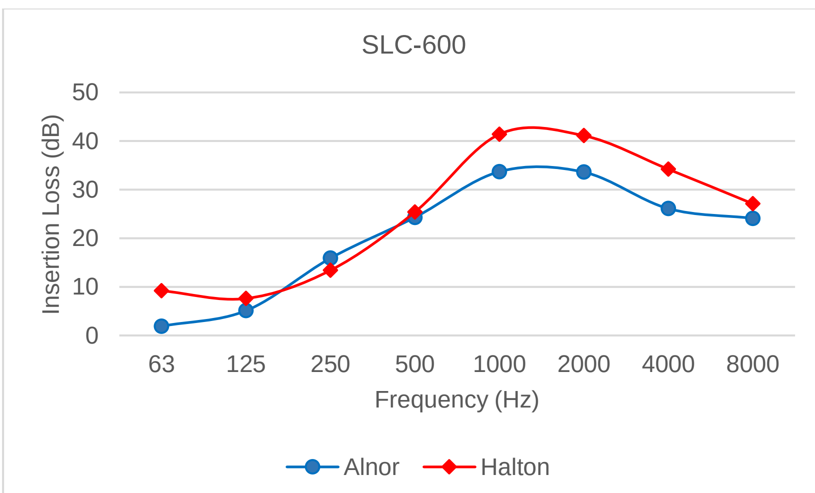


Figure 11. Comparison between Alnor's and Halton's insertion loss for SCL-300 and SLC-600

The insertion loss becomes even higher than expected at frequencies from 500Hz in both samples. Meanwhile, attenuation levels at the range from 125Hz to 500Hz did not meet the expectations. These results with comparison tables were sent to Alnor research and development specialists for further investigations. However, in general, the result was worthy of continued cooperation.

7 CONCLUSION

The main goal of this research was to find a silencer supplier for Halton's needs. To achieve this, a lot of attenuator manufacturers were contacted and, Alnor was ultimately chosen as a suitable supplier. Two rectangular silencer samples were ordered in order to provide two tests and compare manufacturer data with the obtained one. Pressure drop and insertion loss were measured in Halton’s reverberation room.

After the comparison, the difference in pressure loss became clear: in the test situation, pressure loss was twice as high for an SLC-600 and triple higher for an SLC-300 than the value provided by Alnor. At this moment, the reason for the error remains unknown. Therefore, the manufacturer was contacted for further explanation. Surprisingly, the insertion loss was much higher than expected at the frequency range from 500 to 8000 Hz, but at the lower frequencies, the values were insignificantly lower than the manufacturer's data. Nevertheless, Halton was going to continue to cooperate with Alnor.

8 DISCUSSION

During this thesis work, several challenges were encountered. Firstly, considerable time was dedicated to company searching and conducting email interviews with potential suppliers, which proved to be more time-consuming than initially expected. The prolonged duration required to establish connections with suitable manufacturers posed a significant hurdle in the progression of the research. Secondly, a surprising revelation was the deficiency of manufacturers in the European market that aligned with Halton's specific requirements, with only one manufacturer meeting the criteria. This limited selection presented an obstacle to finding suitable partners for collaboration. Thirdly, there was a discrepancy between the expected involvement in conducting tests and the reality of the situation. Rather than actively participating in the testing process, I found myself in the role of receiving final results and focused on researching calculation methods for insertion loss and pressure drop values.

Collection of technical data and MagiCAD and Revit drawings of Alnor's silencers and insertion of all the information into Halton's system will be the next step for the company to start selling silencers. After a few years, Halton will be able to create its attenuator relying on experience with Alnor's silencers. Moving forward, it is recommended that Halton undertake a comprehensive collection of information relating to various manufacturers and their cooperation behaviour to inform future product researchers. This proactive approach will facilitate more informed decision-making and minimize potential communication challenges that arise during the research process.

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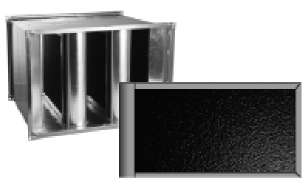
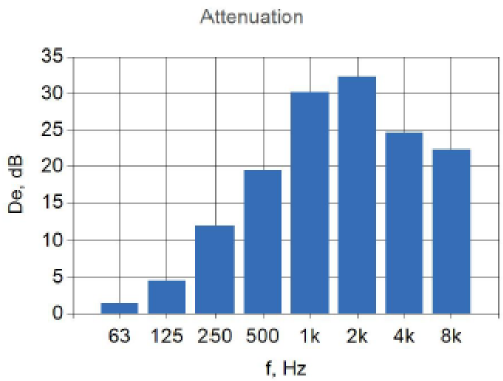
Appendix 1

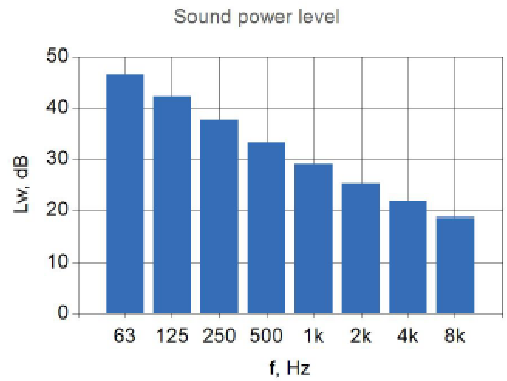
Technical data of silencer SLC-300

SLC - 100 - 2 - 0300 - 0300 - 0600



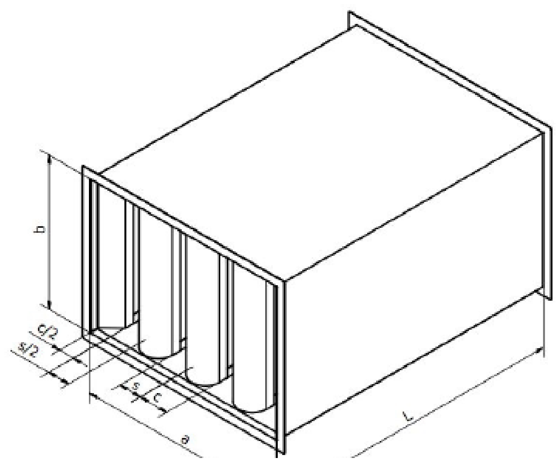
SLC	Material: Galvanized steel sheet
100	Baffle thickness, mm
2	Number of baffles
0300	Width a, mm
0300	Height b, mm
0600	Length L, mm
Pieces	1





f[Hz]	63	125	250	500	1k	2k	4k	8k
De	1.5	4.5	12.1	19.5	30.2	32.3	24.6	22.3
Lw	46.5	42.2	37.6	33.2	29	25.2	21.8	18.7

Volume flow (V)	1000 m3/h
Air velocity (vef)	9.3 m/s
Sound power level (LwA)	31 dB(A)
Pressure drop (dP)	28 Pa
Weight	7.7 kg



Appendix 2

Sound power level tests results

<u>SLC-300</u>

№1

f [Hz]	Lpsrc [dB]	Lpbkg [dB]	Cf1 [dB]	Trev [s]	Lw(A) [dB	Lw [dB]	Huom!	S
50	28.8	34.3	****	3	6.3	35.8	2	X
63	19.4	29.3	****	4.2	-1.7	24.5	2	X
80	26.3	29.7	****	4.4	9.3	30.8	2	X
100	17.9	20.9	****	4.7	2.7	21.8	2	
125	21	17.2	****	4.4	8.8	24.9	2	
160	22.4	13.9	0.7	7.1	9.8	23.2	1	
200	25.5	7.6	0	6	16.7	27.6	0	
250	23	5.9	0	5.8	16.5	25.1	0	
315	25.1	11.9	0	5.7	20.5	27.1	0	
400	23.5	3.4	0	5.2	21	25.8	0	
500	22.7	-1.3	0	5.6	21.4	24.6	0	
630	22.4	-2.8	0	5.7	22.3	24.2	0	
800	19.8	-6	0	6	20.4	21.2	0	
1000	15.6	-4.7	0	6.2	16.9	16.9	0	
1250	11.8	-6.1	0	5.1	14.5	13.9	0	
1600	7.7	-2.9	0	4.5	11.3	10.3	0	
2000	2.7	-5.7	0.8	3.8	6.4	5.2	1	
2500	-2.4	-5.7	****	3.3	2.7	1.4	2	
3150	-4.6	-5.1	****	2.7	1.4	0.2	2	
4000	-5.1	-5.2	****	2.2	1.6	0.6	2	
5000	-4.8	-5.1	****	1.7	2.4	1.9	2	
6300	-4.6	-4.9	****	1.1	3.8	3.9	2	
8000	-4.5	-4.6	****	0.9	3.7	4.8	2	
10000	-4	-4	****	0.7	4.3	6.8	2	
KOKONAISÄÄNITASOT								
Lw(A):	29.4 [dB]							
Lw:	35.1 [dB]							
Lp(A) re 1(	25.4 [dB]							
NR/NC-lul	21/0							

№2

f [Hz]	Lpsrc [dB]	Lpbkg [dB	Cf1 [dB]	Trev [s]	Lw(A) [dB	Lw [dB]	Huom!	S
50	32.4	32.6	****	3	9.9	39.4	2	X
63	23.5	29.5	****	4.2	2.4	28.6	2	X
80	29	27.3	****	4.4	12	33.5	2	X
100	25.3	21.7	****	4.7	10.1	29.2	2	
125	24.3	16.3	0.8	4.4	11.2	27.3	1	
160	25.4	13.5	0	7.1	13.5	26.9	0	
200	27.7	6.7	0	6	18.9	29.8	0	
250	28.5	6.5	0	5.8	22	30.6	0	
315	27.8	11.5	0	5.7	23.1	29.7	0	
400	26.5	3.9	0	5.2	23.9	28.7	0	
500	25	-1.1	0	5.6	23.6	26.8	0	
630	27.1	-3.7	0	5.7	26.9	28.8	0	
800	27	-5.6	0	6	27.6	28.4	0	
1000	23.5	-4.9	0	6.2	24.8	24.8	0	
1250	20.7	-5.5	0	5.1	23.4	22.8	0	
1600	17.8	-2.5	0	4.5	21.4	20.4	0	
2000	13.3	-6	0	3.8	17.7	16.5	0	
2500	8.6	-5.5	0	3.3	13.7	12.4	0	
3150	2.7	-5.1	0.9	2.7	7.8	6.6	1	
4000	-2.3	-5.3	****	2.2	4.4	3.4	2	
5000	-4.2	-5.1	****	1.7	3	2.5	2	
6300	-4.8	-4.9	****	1.1	3.6	3.7	2	
8000	-4.6	-4.6	****	0.9	3.7	4.8	2	
10000	-4	-4.1	****	0.7	4.3	6.8	2	
KOKONAISÄÄNITASOT								
Lw(A):	34.5 [dB]							
Lw:	39.2 [dB]							
Lp(A) re 1(	30.5 [dB]							
NR/NC-lul	27/25							

№3

f [Hz]	Lpsrc [dB]	Lpbkg [dB]	Cf1 [dB]	Trev [s]	Lw(A) [dB]	Lw [dB]	Huom!	S
50	32.9	33.6	****	3	10.3	39.8	2	X
63	32.2	30.6	****	4.2	11.1	37.3	2	X
80	31.9	27.4	****	4.4	14.8	36.3	2	X
100	30	22.4	0.9	4.7	13.9	33	1	
125	30	16.3	0	4.4	17.7	33.8	0	
160	30.3	17.4	0	7.1	18.4	31.8	0	
200	31.5	8.7	0	6	22.7	33.6	0	
250	30.9	8.4	0	5.8	24.4	33	0	
315	30.2	12.5	0	5.7	25.6	32.2	0	
400	31.1	4	0	5.2	28.6	33.4	0	
500	30.7	-2	0	5.6	29.4	32.6	0	
630	31.4	-6.2	0	5.7	31.3	33.2	0	
800	32.1	-7.2	0	6	32.7	33.5	0	
1000	28.9	-5.4	0	6.2	30.1	30.1	0	
1250	26.5	-6.2	0	5.1	29.2	28.6	0	
1600	23.8	-2.2	0	4.5	27.4	26.4	0	
2000	21	-6.3	0	3.8	25.4	24.2	0	
2500	16.6	-5.6	0	3.3	21.7	20.4	0	
3150	10.6	-5.6	0	2.7	16.6	15.4	0	
4000	4.6	-4.9	0.5	2.2	10.7	9.7	1	
5000	-0.2	-5.1	****	1.7	7	6.5	2	
6300	-3.6	-4.8	****	1.1	4.8	4.9	2	
8000	-4.3	-4.7	****	0.9	4	5.1	2	
10000	-3.9	-4.2	****	0.7	4.4	6.9	2	
KOKONAISÄÄNITASOT								
Lw(A):	39.4 [dB]							
Lw:	43.6 [dB]							
Lp(A) re 1(	35.4 [dB]							
NR/NC-lul	32/31							

№4

f [Hz]	Lpsrc [dB]	Lpbkg [dB	Cf1 [dB]	Trev [s]	Lw(A) [dB	Lw [dB]	Huom!	S
50	30.8	35.2	****	3	8.2	37.7	2	X
63	33.2	28.7	****	4.2	12.1	38.3	2	X
80	32.2	29.1	****	4.4	15.2	36.7	2	X
100	28.3	22.1	1.2	4.7	11.9	31	1	
125	31.5	16.4	0	4.4	19.2	35.3	0	
160	34.6	15.7	0	7.1	22.7	36.1	0	
200	34.6	9.1	0	6	25.8	36.7	0	
250	33.7	9.3	0	5.8	27.2	35.8	0	
315	34.6	12.7	0	5.7	30	36.6	0	
400	34.3	3.6	0	5.2	31.7	36.5	0	
500	35.4	-1	0	5.6	34	37.2	0	
630	35.6	-3.7	0	5.7	35.4	37.3	0	
800	36.7	-6.2	0	6	37.3	38.1	0	
1000	34.1	-5.7	0	6.2	35.4	35.4	0	
1250	32.6	-6	0	5.1	35.2	34.6	0	
1600	30.6	-3.5	0	4.5	34.2	33.2	0	
2000	28.1	-6.2	0	3.8	32.5	31.3	0	
2500	24.6	-5.8	0	3.3	29.7	28.4	0	
3150	20	-5.4	0	2.7	26	24.8	0	
4000	14.3	-5.2	0	2.2	21	20	0	
5000	9.4	-4.9	0	1.7	16.6	16.1	0	
6300	3.8	-4.7	0.7	1.1	11.5	11.6	1	
8000	-1.7	-4.5	****	0.9	6.6	7.7	2	
10000	-3.6	-4	****	0.7	4.7	7.2	2	
KOKONAISÄÄNITASOT								
Lw(A):	44.4 [dB]							
Lw:	47.3 [dB]							
Lp(A) re 1(	40.4 [dB]							
NR/NC-lul	37/36							

№5

f [Hz]	LpII [dB]	LpI [dB]	Dlim	Cf2 [dB]	D [dB]	Huom!
50	37.8	32.4	11.7	1	6.4	1
63	40.5	34.5	37.3	0	6	0
80	38.7	39.8	44.6	0	-1.1	0
100	46.5	44.4	48.4	0	2	0
125	50	45.3	64.5	0	4.7	0
160	51	46.9	61.7	0	4.1	0
200	53.8	45.7	70.2	0	8.2	0
250	53.4	43.6	64	0	9.8	0
315	52.2	39.6	69.6	0	12.6	0
400	51.6	35.7	61.2	0	15.9	0
500	50.9	32.8	57.2	0	18.1	0
630	51.9	26	57.9	0	26	0
800	51.1	17	61.1	0	34	0
1000	48	8.3	68.8	0	39.7	0
1250	48.6	7.9	60.4	0	40.7	0
1600	48.1	8.8	53	0	39.3	0
2000	51	11.8	46	1	40.3	1
2500	51	12.9	45.4	1	39.1	1
3150	48.5	17.3	41.5	0	31.2	0
4000	45	20	46.5	0	25	0
5000	48.7	23	48.9	0	25.7	0
6300	45.2	22.7	47.7	0	22.5	0
8000	42.7	22.3	49.1	0	20.4	0
10000	37.7	17	47.4	0	20.7	0

SLC-600

№6

f [Hz]	Lpsrc [dB]	Lpbkg [dB	Cf1 [dB]	Trev [s]	Lw(A) [dB]	Lw [dB]	Huom!	S
50	30.7	30.1	****	4.8	6.2	35.7	2	X
63	27.4	22.1	****	4.4	6.1	32.3	2	X
80	32.2	29.9	****	4.9	14.6	36.1	2	X
100	20.3	14.7	****	4.4	5.3	24.4	2	
125	23	11.8	0	5.2	10.1	26.2	0	
160	24.6	8.1	0	6	13.5	26.9	0	
200	25.9	4.4	0	5.5	17.5	28.4	0	
250	24.5	3.4	0	5.8	17.9	26.5	0	
315	22.7	0.9	0	5.6	18.2	24.8	0	
400	23.7	2	0	5.1	21.3	26.1	0	
500	22	-6.2	0	5.3	21	24.2	0	
630	20.9	-6.5	0	5.6	20.8	22.7	0	
800	19.2	-6.8	0	5.9	19.9	20.7	0	
1000	15.7	-6.8	0	6.1	17	17	0	
1250	11.7	-5.7	0	5.2	14.3	13.7	0	
1600	6.7	-4.7	0	4.7	10	9	0	
2000	1.3	-6.6	0.9	3.9	4.8	3.6	1	
2500	-3.2	-5.8	****	3.4	1.8	0.5	2	
3150	-5.4	-5.3	****	2.8	0.4	-0.8	2	
4000	-5.3	-4.7	****	2.4	1	0	2	
5000	-5.1	-5.1	****	1.9	1.6	1.1	2	
6300	-5.1	-4.9	****	1.3	2.7	2.8	2	
8000	-4.6	-4.4	****	1	3.4	4.5	2	
10000	-4.1	-4	****	0.7	3.8	6.3	2	
KOKONAISÄÄNITASOT								
Lw(A):	29.0 [dB]							
Lw:	35.7 [dB]							
Lp(A) re 1(	25.0 [dB]							
NR/NC-lul	21/0							

№7

f [Hz]	Lpsrc [dB]	Lpbkg [dB	Cf1 [dB]	Trev [s]	Lw(A) [dB	Lw [dB]	Huom!	S
50	29.1	33	****	4.8	4.5	34	2	X
63	25.7	25	****	4.4	4.3	30.5	2	X
80	30.5	30.1	****	4.9	12.9	34.4	2	X
100	23.1	19.5	****	4.4	8.2	27.3	2	
125	24.8	14.4	0	5.2	11.9	28	0	
160	24.6	11.1	0	6	13.5	26.9	0	
200	28	12.2	0	5.5	19.6	30.5	0	
250	27.6	6.6	0	5.8	21	29.6	0	
315	29.3	3.6	0	5.6	24.8	31.4	0	
400	27.6	-0.2	0	5.1	25.2	30	0	
500	27.5	-5.7	0	5.3	26.5	29.7	0	
630	26.6	-6	0	5.6	26.5	28.4	0	
800	25.3	-6.6	0	5.9	26.1	26.9	0	
1000	22.7	-6.5	0	6.1	24	24	0	
1250	19.6	-6.3	0	5.2	22.2	21.6	0	
1600	15.3	-4.9	0	4.7	18.6	17.6	0	
2000	10.4	-6.1	0	3.9	14.8	13.6	0	
2500	4.8	-5.6	0	3.4	9.8	8.5	0	
3150	-1	-5.4	****	2.8	4.8	3.6	2	
4000	-4.3	-5.2	****	2.4	2	1	2	
5000	-4.7	-5	****	1.9	2	1.5	2	
6300	-4.9	-4.8	****	1.3	2.8	2.9	2	
8000	-4.6	-4.8	****	1	3.4	4.5	2	
10000	-4.1	-4.2	****	0.7	3.8	6.3	2	
KOKONAISÄÄNITASOT								
Lw(A):	34.4 [dB]							
Lw:	39.4 [dB]							
Lp(A) re 1(	30.4 [dB]							
NR/NC-lul	26/24							

№8

f [Hz]	Lpsrc [dB]	Lpbkg [dB	Cf1 [dB]	Trev [s]	Lw(A) [dB	Lw [dB]	Huom!	S
50	31.4	27.9	****	4.8	6.9	36.4	2	X
63	27.6	26	****	4.4	6.3	32.5	2	X
80	32.5	31	****	4.9	14.9	36.4	2	X
100	26.1	22.9	****	4.4	11.1	30.2	2	
125	28.7	19.5	0.6	5.2	15.1	31.2	1	
160	27.6	15.8	0	6	16.5	29.9	0	
200	30.3	14.1	0	5.5	21.8	32.7	0	
250	31.5	10.1	0	5.8	24.9	33.5	0	
315	31.8	6.4	0	5.6	27.3	33.9	0	
400	31.5	4.3	0	5.1	29	33.8	0	
500	30.8	0.7	0	5.3	29.7	32.9	0	
630	32.2	-1.9	0	5.6	32.1	34	0	
800	31.1	-5.1	0	5.9	31.9	32.7	0	
1000	28.7	-6.3	0	6.1	30.1	30.1	0	
1250	26.9	-6.6	0	5.2	29.5	28.9	0	
1600	22.6	-5.4	0	4.7	25.9	24.9	0	
2000	18	-6.4	0	3.9	22.3	21.1	0	
2500	13.3	-5.8	0	3.4	18.3	17	0	
3150	7.5	-5.4	0	2.8	13.3	12.1	0	
4000	1.2	-5	1.3	2.4	6.2	5.2	1	
5000	-2.9	-5.1	****	1.9	3.8	3.3	2	
6300	-4.4	-4.9	****	1.3	3.3	3.4	2	
8000	-4.3	-4.5	****	1	3.6	4.7	2	
10000	-4.1	-4	****	0.7	3.9	6.4	2	
KOKONAISÄÄNITASOT								
Lw(A):	39.3 [dB]							
Lw:	43.2 [dB]							
Lp(A) re 1(	35.3 [dB]							
NR/NC-lul	32/31							

№9

f [Hz]	Lpsrc [dB]	Lpbkg [dB	Cf1 [dB]	Trev [s]	Lw(A) [dB	Lw [dB]	Huom!	S
50	31.6	30	****	4.8	7.1	36.6	2	X
63	31.9	24.2	0.9	4.4	9.7	35.9	1	X
80	34.5	30.3	****	4.9	17	38.5	2	X
100	27.3	22.4	****	4.4	12.4	31.5	2	
125	34.2	19	0	5.2	21.3	37.4	0	
160	33.7	17.1	0	6	22.6	36	0	
200	35.1	18.2	0	5.5	26.7	37.6	0	
250	35	14.7	0	5.8	28.5	37.1	0	
315	36.3	12.8	0	5.6	31.8	38.4	0	
400	35.6	11.6	0	5.1	33.1	37.9	0	
500	36	8.6	0	5.3	35	38.2	0	
630	35.2	6.3	0	5.6	35.1	37	0	
800	35.6	1.9	0	5.9	36.4	37.2	0	
1000	33.5	-1.5	0	6.1	34.9	34.9	0	
1250	32.9	-4.4	0	5.2	35.5	34.9	0	
1600	29.8	-3.8	0	4.7	33.2	32.2	0	
2000	26	-5.8	0	3.9	30.3	29.1	0	
2500	22.1	-5.8	0	3.4	27.1	25.8	0	
3150	17.3	-5.2	0	2.8	23	21.8	0	
4000	11.2	-5.1	0	2.4	17.5	16.5	0	
5000	4.9	-4.9	0.4	1.9	11.2	10.7	1	
6300	-1.4	-4.6	****	1.3	6.3	6.4	2	
8000	-4	-4.6	****	1	4	5.1	2	
10000	-4	-4	****	0.7	3.9	6.4	2	
KOKONAISÄÄNITASOT								
Lw(A):	44.2 [dB]							
Lw:	47.8 [dB]							
Lp(A) re 1(	40.2 [dB]							
NR/NC-lul	37/36							

№10

f [Hz]	LpII [dB]	LpI [dB]	Dlim	Cf2 [dB]	D [dB]	Huom!
50	36.7	30.3	11.7	2	6.4	1
63	49.7	38.2	37.3	0	11.5	0
80	52.1	40	44.6	0	12.1	0
100	50.1	40.4	48.4	0	9.7	0
125	49.7	41.3	64.5	0	8.4	0
160	50.7	45.1	61.7	0	5.6	0
200	52.7	42.4	70.2	0	10.3	0
250	51.7	36.9	64	0	14.7	0
315	51.8	31.8	69.6	0	20	0
400	51	29.1	61.2	0	21.9	0
500	49.9	23.1	57.2	0	26.9	0
630	50.9	13.7	57.9	0	37.2	0
800	49.1	8.9	61.1	0	40.2	0
1000	47.9	5.8	68.8	0	42.1	0
1250	49	6.7	60.4	0	42.3	0
1600	48.1	7.2	53	0	40.9	0
2000	50.3	9	46	2	43.3	1
2500	49.8	8.8	45.4	2	43	1
3150	48	9.1	41.5	****	38.9	2
4000	45.8	14.4	46.5	0	31.4	0
5000	48.9	13.6	48.9	0	35.3	0
6300	45.3	13.8	47.7	0	31.5	0
8000	44	17.1	49.1	0	26.9	0
10000	39	13.9	47.4	0	25.1	0