NOISE CONTROL

AN INTRODUCTION TO SOUND: HOW TO PREVENT NOISE PROBLEMS IN YOUR HVAC SYSTEM

HEINEN & HOPMAN

"

How can a loud sound be more comfortable?

INTRO

There is no sound in space. Space is a vacuum so there is no medium to transfer the sound waves. Creating a vacuum would solve all your noise problems. But then again, that would not be very functional. And comfortable. The main goal of noise control is to create a comfortable environment. That doesn't mean there cannot be any sound.

Sometimes the sound of a running air conditioning system is a welcome phenomenon. Because it masks other, more annoying sounds.

How this works and why it works is written in this document.

This white paper is about noise in HVAC systems and how to control it. Especially HVAC systems in the maritime sector where noise level requirements demand a certain level of comfort.

> **The most silent installation is not always the most comfortable.**

CHAPTERS

SUMMARY

**When sound is judged to be unpleasant, loud or disruptive to hearing, it is called noise. As sound and noise control has a major impact on comfort levels, we aim to dig deeper into this topic. What exactly is sound? How do we experience discomfort? Which types of noise can be defined and what can we do to control them?
In the first section, we explain what sound is. The second section covers comfort and the effect of noise. The three different types of noise are discussed in the third section, while the final section examines solutions to prevent or reduce noise issues.**

By exploring the topic of sound, we will give you a better understanding of exactly what noise is, including:

- The properties of a soundwave;
- The meaning of sound and why a change of two decibels can make such a major difference.
- Why certain sounds are more irritating than others.
- The three types of noise and how to solve the problems you might face.

> How do we experience discomfort?

PART 1
WHAT IS SOUND?

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WHAT IS SOUND?

WHAT IS SOUND?

Sound comes in many different forms. It can be harsh and loud, or soft and gentle. Noise can be high and shrill, or low and deep. Sometimes it manifests as a pure note, sometimes as static.

What exactly is sound? In physical terms, sound is a pressure increase which travels through a medium such as gas, liquid or a solid in the form of a wave. You could say that a wave is a disturbance that propagates through space. But what does this look like in reality? Well, imagine there is a speaker standing in the middle of a room. A speaker produces sound through the miniscule movements of its woofer – this is called oscillation. As the woofer moves rapidly up and down, the molecules in its direct vicinity move in tandem with it. This causes pressure to increase as the molecules are pressed together, resulting in a chain reaction of oscillating molecules that travel through space in the form of a wave until they reach your eardrum. This is how sound reaches us.

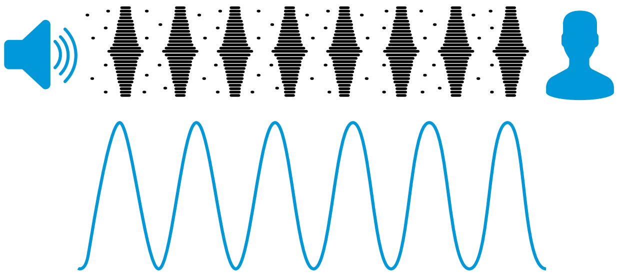
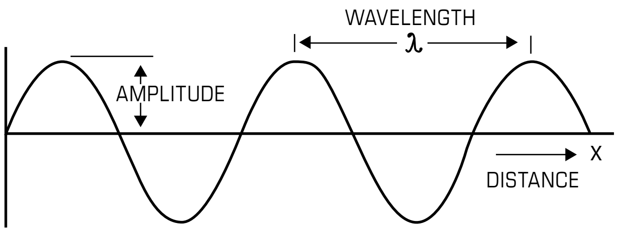
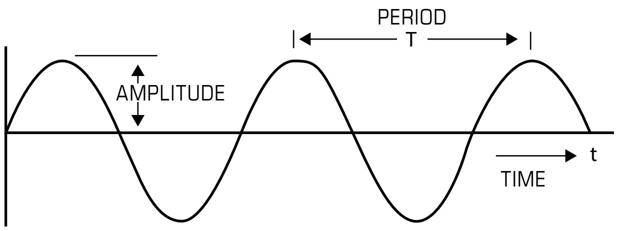


Image 1: Woofer with molecule pressure increase.



If we want to figure out sound, we first need to figure out the properties of a wave.



AMPLITUDE

The height of a soundwave measured from the baseline is called the amplitude. This reflects the degree of pressure increase and corresponds to the loudness of the sound: the larger the amplitude, the louder the sound will be.

PERIOD

A wave has a beginning and an end. Initially it increases until it reaches its maximum point, or crest. From there, it descends to the lowest point – the trough – after which it ascends again. A wave is defined as one full loop up and down.

FREQUENCY

A wave which consists of only one period is called a pulse. Sounds always have more periods, however. The frequency measures the number of periods per second – how many crests and troughs there are in the timespan of one second. Frequency is expressed in hertz: if there are 20 periods in a second, the frequency is 20 Hz.

WAVELENGTH

This tells us how far the wave has travelled after one period. It is the distance which a single period travels, or the displacement of the wave. The longer the wavelength, the lower the sound.

- **Frequency f = number of oscillations per second:** **Frequency** $f = \frac{1}{T}$ **[Hz]**
- **Period T = number of seconds per oscillation:** **Period** $T = \frac{1}{f}$ **[sec]**

For example: A wave is traveling with a frequency of 25 Hz and a velocity of 100m/s, what is its wavelength?

- **Wavelength = how far the wave has travelled after 1 period**

$$\text{Velocity } v = \frac{\text{distance}}{\text{time}} = \frac{\text{wavelength}}{\text{period}} = \frac{\lambda}{T}$$

$$v = \frac{\lambda}{T} = \lambda * \frac{1}{T} = \lambda * f$$

$$\lambda = \frac{v}{f} = \frac{100}{25} = 4 \text{ meter}$$

PART 2
WHAT IS ACOUSTIC COMFORT?

PART 2

WHAT IS ACOUSTIC COMFORT?

IT'S ALL A MATTER OF COMFORT

The dictionary definition of 'comfort' is a pleasurable state of wellbeing, a condition in which one effortlessly feels good.

It can also – and this is probably best applicable to HVAC – be described as the absence of discomfort. When a system is not intrusively audible, everyone is happy. The issues start when the presence of a system becomes noticeable. It's also important to remember that comfort is not the same as luxury.

If we define acoustic comfort as a situation where one doesn't notice the running HVAC system, the comfort level will depend on the situation in which we find ourselves. Every situation has its own noise criteria, and what is comfortable at certain times will not automatically be experienced as such at others. Of course, this isn't completely subjective either: some smart people have thought about this and given us guidelines for noise requirements. An example is the Det Norske Veritas (DNV) comfort class document from which the tables below are taken. Let's have a look:

TABLE A2 CARGO SHIPS <10 000 GT1 - MAXIMUM NOISE LEVELS IN DB(A)			
LOCATIONS	Comfort rating number (crn)		
	1	2	3
WHEELHOUSE	**60**	**60**	**65**
RADIO ROOM	**55**	**55**	**60**
CREW CABINS	**50**	**55**	**60**
CREW PUBLIC SPACES	**55**	**60**	**65**
HOSPITAL	**55**	**58**	**60**
OFFICES	**60**	**60**	**65**
MACHINERY CONTROL ROOMS	**65**	**70**	**75**
OPEN DECK RECREATION	**70**	**73**	**75**
1) For working areas, navigation spaces, service spaces, machinery rooms and spaces not specified, the reguirements of IMO MSC 337(91) Code on noise levels on board ships apply			

Table 1: Noise requirements for cargo ship

TABLE A5 YACHT OWNER & GUEST AREAS MAXIMUM NOISE LEVELS IN DB(A)						
LOCATIONS	Comfort rating number (crn)					
	in harbour condition			transit conditions		
	1	2	3	1	2	3
SLEEPING ROOMS	**35**	**40**	**45**	**-**	**-**	**-**
LOUNGES / SALOONS	**40**	**45**	**50**	**53**	**58**	**62**
OUTDOOR RECREATION AREAS	**50**	**55**	**60**	**75**	**80**	**85**
NAVIGATION BRIDGE	**-**	**-**	**-**	**60**	**60**	**65**

Table 2: Noise requirements Yacht

The first row indicates the comfort rating, where 1 is highest and 3 is lowest. Now notice the differences in cabins/sleeping rooms. Level 1 corresponds to 50 decibels on a cargo ship and 25 on a luxury yacht. That's a major difference, as we will see when discussing decibels below.

These tables seem to imply that the quieter a system the better, because comfort rating 1 has lower decibel levels than ratings 2 and 3. But this is not entirely true: the quietest installation is not always the most comfortable as one sound can mask another, more irritating, one. An example of this is the public spaces on a vessel or an office environment. The ambient sound of an HVAC system can conceal background noises present in public areas, offices or even the noise of engines running. But how can a sound being louder be better for the comfort level? The answer is found in the way we experience sound.

Soft and gentle

GIVE ME SOFT DECIBELS AND GENTLE FREQUENCIES

Some noises are more irritating than others. For example, the soft beep of your alarm clock is more annoying than the sound of music coming from a hi-fi system, even if the latter is louder. The degree of discomfort caused by a sound depends on two properties: volume and frequency.

Let's start with volume. The property of volume is decibel which measures the degree of pressure increase – or the amplitude – corresponding with the loudness of a sound. The higher the pressure, the louder the volume.

For there to be a pressure increase, a medium must be affected by some kind of energy or force.

$$\textbf{Sound [dB(A)]}\ \beta = 10 * \log_{10} \frac{I}{10^{-12} \frac{W}{m^2}}$$

Don't be intimidated by this formula, or the fact that there is a logarithm involved in it. It's not as difficult as it looks. Let's go through the equation from the beginning.

- β is the number of dBs or decibels;
- The 10 simply converts bels to decibels (in the same way as 1/10 of a litre is a decilitre);
- The logarithm is there to convert the outcome into a more easily manageable number;
- I is the numerator and represents the intensity of a sound wave, it is defined as power divided by area in watts per square metre [$\frac{W}{m^2}$];
- The denominator is 10 to the power of -12 watts per square metre and represents the threshold of human hearing. It is the softest sound that a human ear can pick up.

Ten to -12 is incredibly small: we are talking about one trillionth of a watt. It shows just how unbelievably sensitive the human ear is. On the other side of the spectrum, the loudest noise a human can comfortably hear is one watt per square metre: anything louder starts to hurt. You can see that there is an enormous gap between the quietest and the loudest sound we can hear – from 0.000000000001 to 1. This is why we use logarithms to transform very large numbers into small, convenient ones.

The other property of sound is frequency, which is the number of periods per second. A high frequency results in a high-pitched sound and a low frequency in a low-pitched one. Every sound you hear is characterised by a combination of intensity, or loudness, and frequency, or pitch. This combination defines how disturbing a noise is. For example see the diagram below, a sound with a volume of 30 dB and a frequency of 1000 Hz is more unpleasant than a sound with 40 dB and 125 Hz.

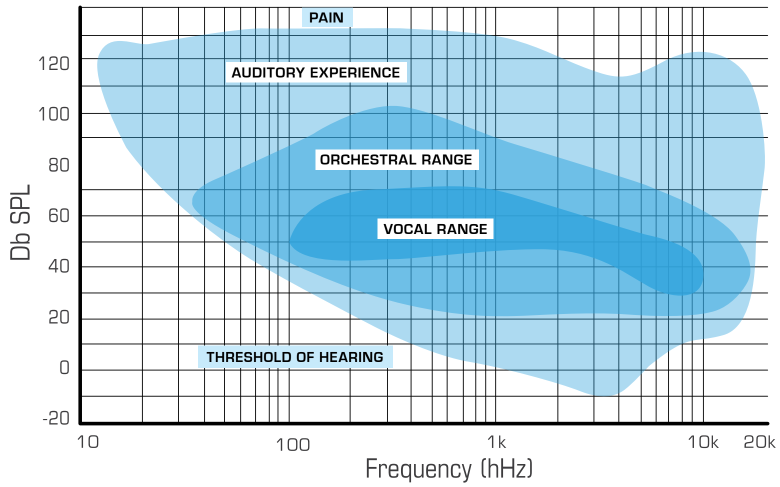


Image 1: Spectrum of human hearing

In reality, no sound consists of a single frequency. Every air handling unit, fan or electric motor produces noise containing multiple frequencies, each with their own intensity. A clear overview of this is provided by a tool called the octave band. The diagram below shows sound intensity against frequency. Each column covers a band of frequencies, ranging from 31 to 16,000 Hz.

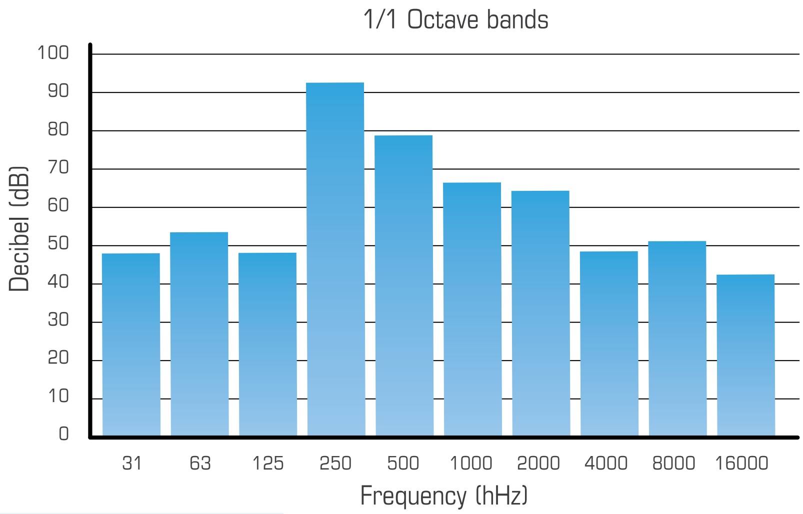


Image 2: Octave band

There are powerful instruments which can measure the sound level at every frequency. We will take a look at these in the next chapter where we talk about three different sorts of noises which are commonly found in our sector.

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PART 3
THREE TYPES OF NOISE

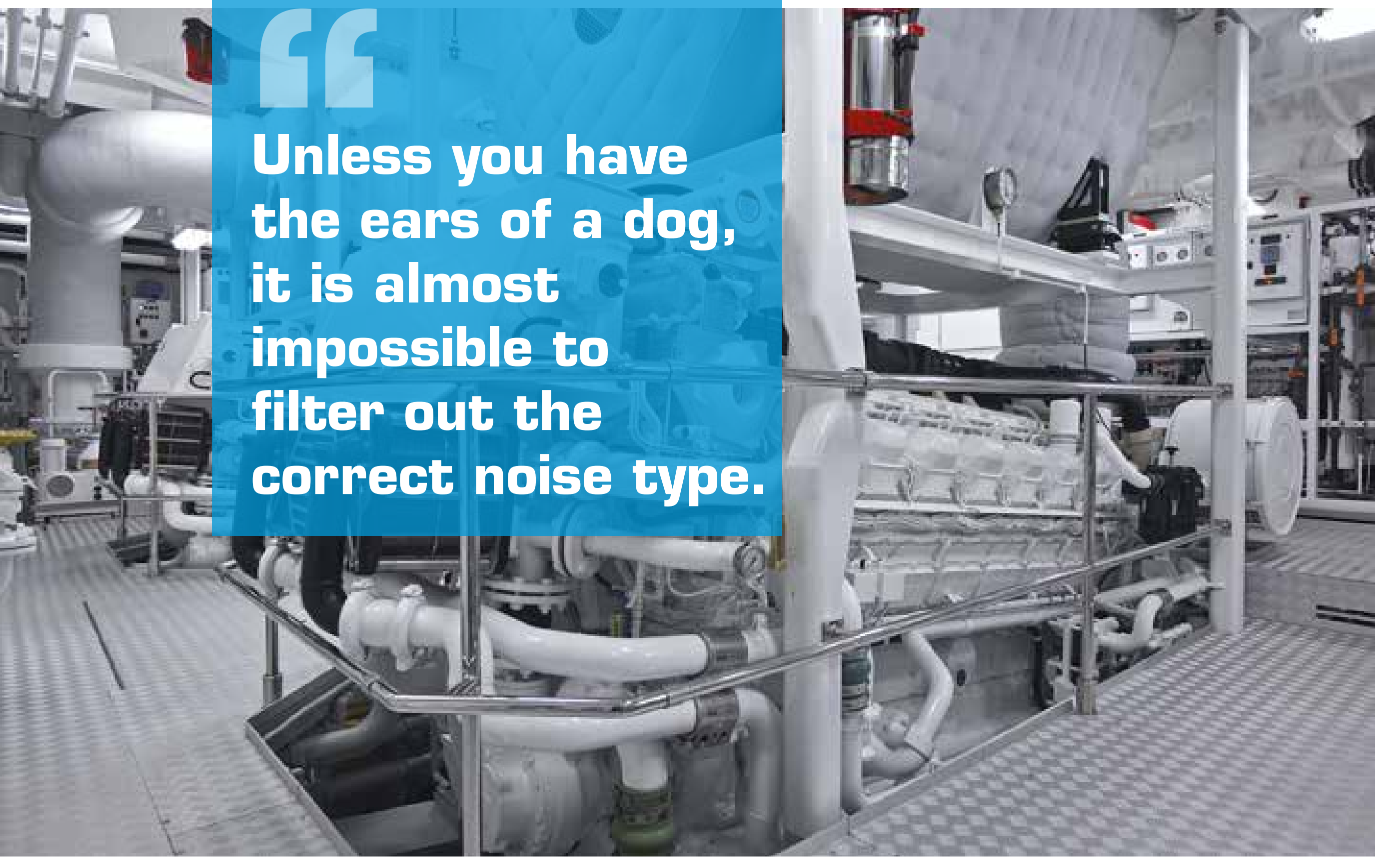
3

PART 3

THREE TYPES OF NOISE

WALL OF SOUND

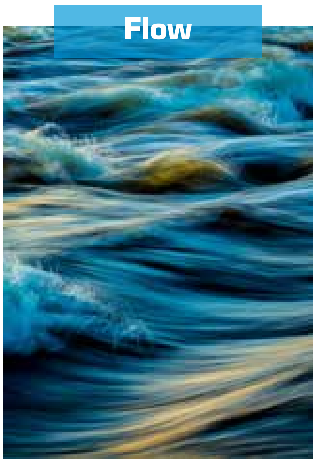
The following is a story of one of our commissioning engineers. A couple of years ago he attended the sea trial of a superyacht. As the vessel cruised towards its destination, the coastline slowly disappeared in the distance. On his way to the galley, he passed the engine room and for a moment, stood still before the door. Muffled sounds and squeaky noises where audible through the massive door. Although he had no business there, curiosity incited him to take a look inside. He opened the door and a wall of sound washed over him!



> **Unless you have the ears of a dog, it is almost impossible to filter out the correct noise type.**

It seemed like this enormous wall of noise was a single sound, like one thundering roar. But when he listened carefully, he could hear different components. He realised this was not just one sound, but a blend of noises all mixed together. There was the pounding of engines, the hiss of pumps and the thundering of air through gigantic ducts near the ceiling.

The same goes for HVAC systems: walk inside a fan room and you will notice that all the different processes each produce their own noise. If you want to isolate a noise, you first need to identify its origin. Installation technicians separate three different types of noise, namely:



MECHANICA NOISE

When a fan, pump or compressor is running, electrical energy is transferred into work. Bearings are rolling, pistons pumping and screws turning: the machine is doing its job. As the gears move, there is contact between materials, which causes friction and therefore air pressure difference in the direct vicinity of the machine.

FLOW NOISE

The product of a running fan is the transportation of air through ducts and pipes. Air is a gas that consists of different molecules, each of which has its own mass and can collide with others to cause friction and turbulence. This is similar to the solid components of a compressor, only on a micro level.

VIBRATIONAL NOISE

As the name implies, these are noises caused by vibrations. While this essentially applies to all sound, even mechanical or air flow noise, we define vibrational noise separately because it can be particularly troublesome. An example of this type of noise are resonating ducts.

TO MEASURE IS TO KNOW

If you have a noise problem somewhere in the cabin or public space, you could listen very carefully and try to localise it. But unless you have excellent hearing, you may struggle to filter out the exact noise you're looking for. In our previous chapter, we discussed how sounds are defined by their frequency and loudness. We can use these properties to define and localise any particular sound. A spectrum analyser can be used to display loudness as a function of frequency, as shown below.

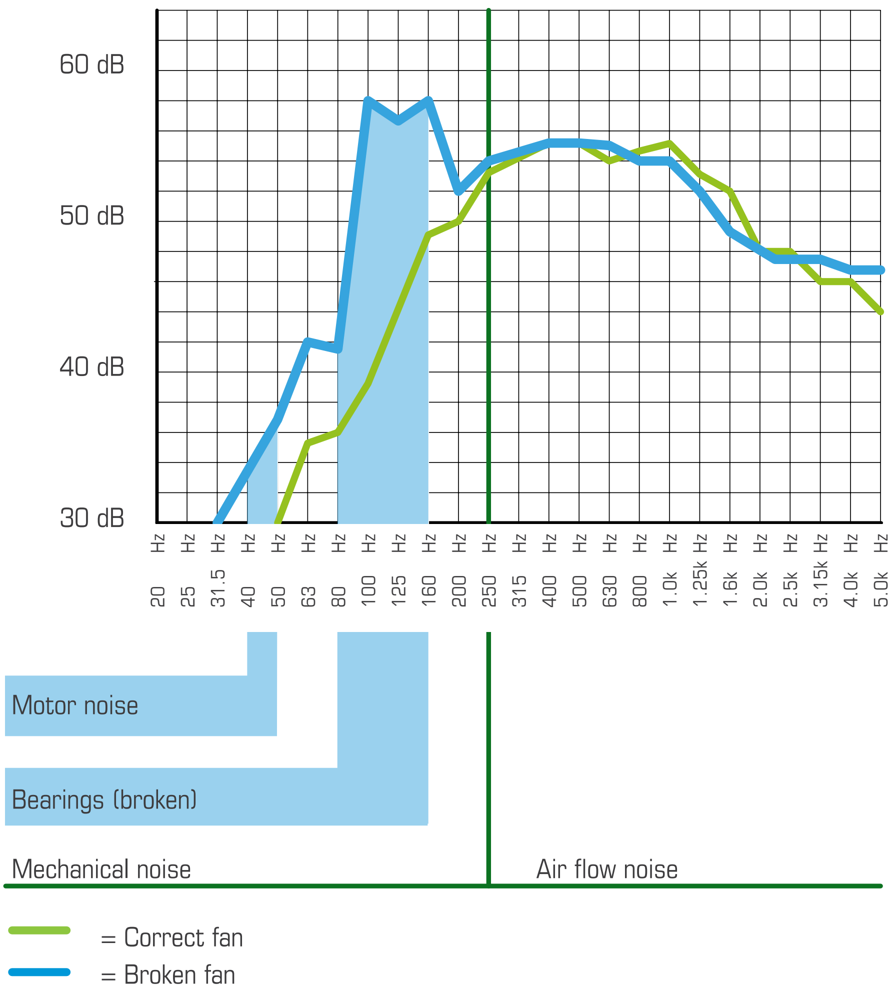


Image 1: Spectrum analysis

This is an example of a fan. The green line represents a fan that operates normally. The blue line is the same fan but with broken bearings. Notice that the intensity of the latter peaks at lower frequencies. In other words, when you see a peak in loudness at a low frequency, you're probably hearing a mechanical noise. Disruptive air flow due to turbulence peaks at a higher frequency. A spectrum analyser enables you to pinpoint the type of noise causing the problem. In our final chapter, we will discuss the solutions for all three noise types.

PART 4
REDUCING HVAC NOISE ISSUES

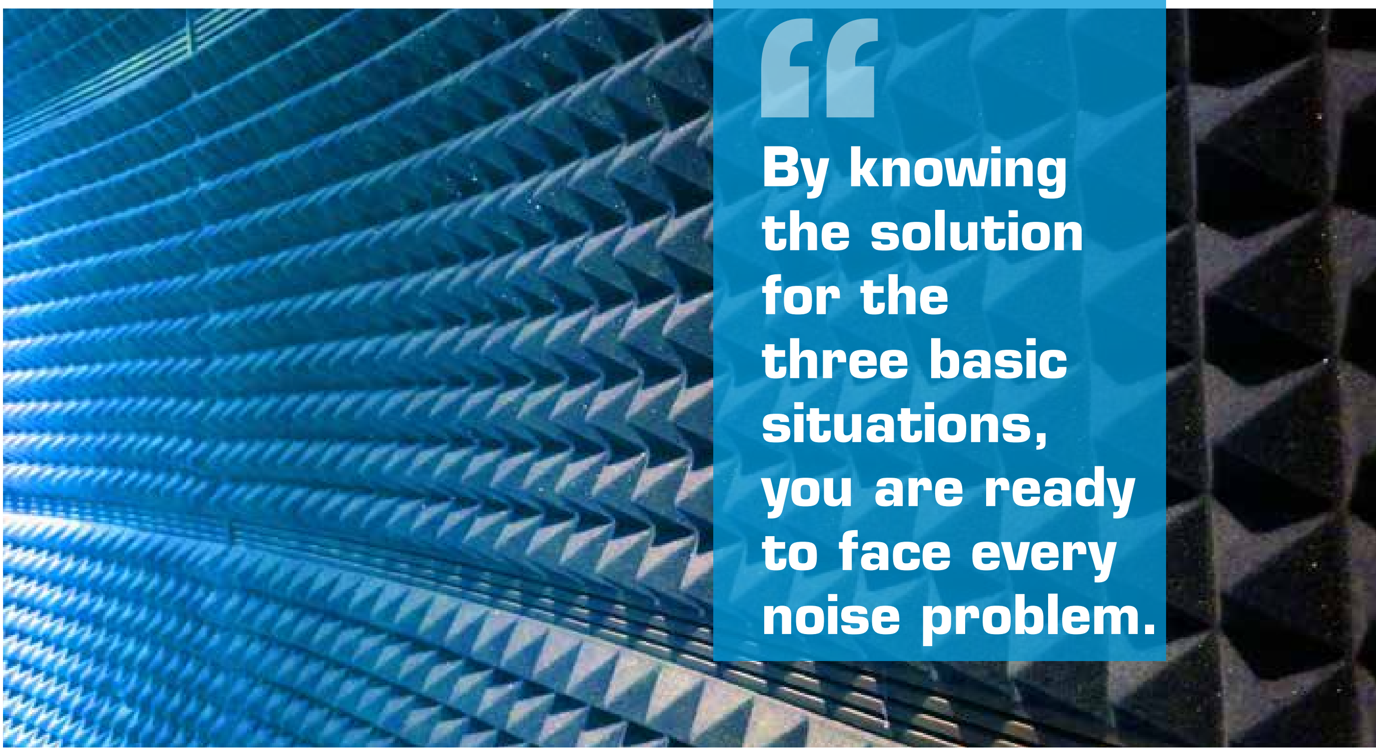
PART 4

REDUCING HVAC NOISE ISSUES

Now we know the three types of noise from a theoretical point of view. As has been discussed in chapter 3. But how does it manifest itself in reality? How does one recognise a mechanical sound and – more importantly - how can it be solved?

THE SITUATION

Imagine a situation with two cabins, both supplied with air by a centrifugal fan in the neighbouring room. I am going to use this situation to describe each of the sound issues and their solutions. We will go through every type of noise step by step: first the problem, then the solution.



"By knowing the solution for the three basic situations, you are ready to face every noise problem.

MECHANICAL NOISE

The centrifugal fan is pumping air into rooms A and B. Although the fan is placed inside a separate room, mechanical noise can be heard through the bulkheads, especially in room A, because this room is next to the fan room. The source of the noise is the fan itself, and to reduce the noise, we must insulate the fan. Image 2 shows the same situation with a sound-dampening box. Another option is to insulate the entire room.

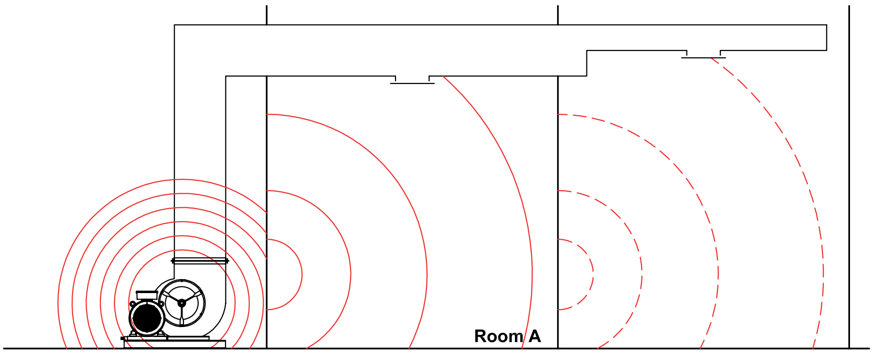


Image 1: Mechanical noise

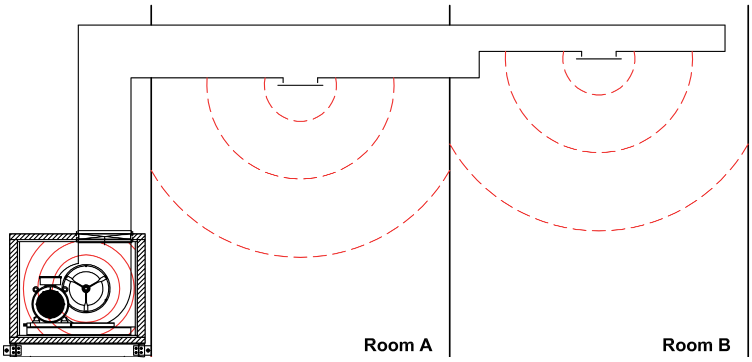


Image 2: Fan placed in sound box

The mechanical fan noise is isolated by the box and soundwaves will not penetrate the bulkhead. However, as the rooms are connected with an air duct, soundwaves traveling through the air supply can still enter the room.

To reduce the noise, we can place a sound damper in the duct (see image 3, next page). The longer the damper the better, especially with mechanical noise, as the frequency is low and the wave lengths are long.

AIR FLOW NOISE

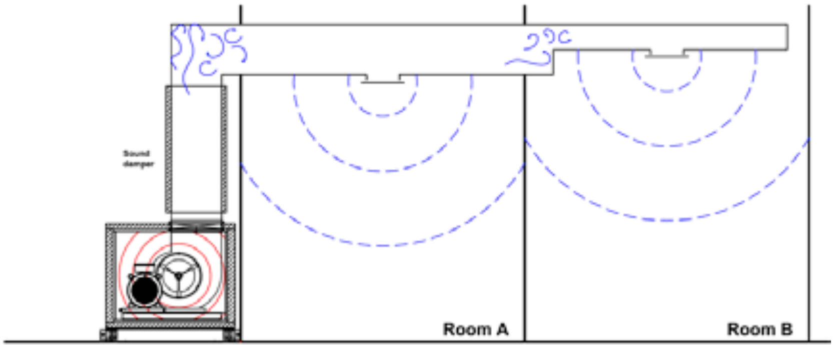


Image 3: Air flow noise

Ideally the air flow is laminar, which means the air molecules travel through the duct in layers. Distortions in the ducting system – such as bends, bottlenecks or HVAC equipment – can cause the air flow to become turbulent (see image 3). Air molecules spin around in the duct, humming and swooshing, which causes air flow noise. Turbulent air can be caused by bad duct design or high speeds inside the duct.

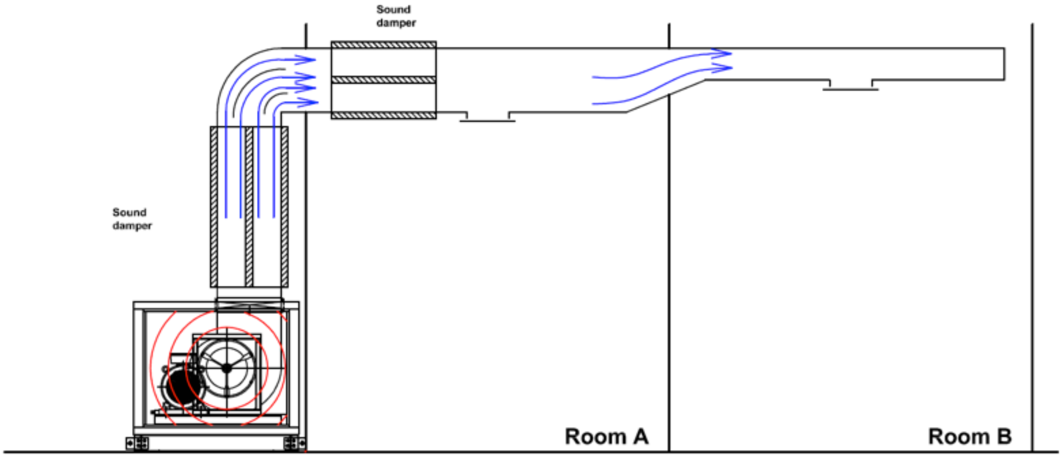


Image 4: Dampers placed in ducting

To prevent air from becoming turbulent, the ducting system has to be adjusted to minimise resistance. For example a 90° bend instead of an angle bend in the system. Make sure the bends are as curved as possible, guiding the air into the right direction while avoiding collisions with the sides. You can also use blades inside the bend to guide the air. Another option is to place a sound damper before and after the bend. Dividing the dampers into different sections forces the air into layers and causes it to become laminar again; see image 4.

VIBRATIONAL NOISE

The source of vibrations is moving parts in the system. The fan rotates at speeds of 3600 rpm and the pressure fluctuates between its air intake and outlet. All these processes cause vibrations, which travel through the floor on which it stands and through the ducts, causing them to resonate. In addition, as the fan box is positioned against the wall it makes contact with the bulkhead and transfers vibrations to the adjacent room; see image 5.

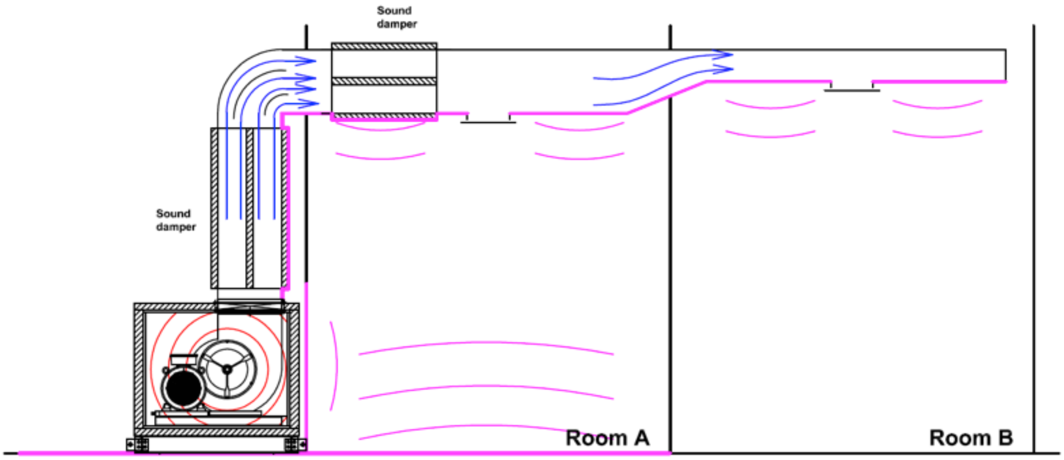


Image 5: Vibrational noise

Obviously, we cannot stop the fan from moving. What we can do is stop the vibrations from being transferred to the surroundings. First of all, we have to make sure the fan box is not connected to anything except the floor: no contact with bulkheads, walls or anything else. Second, we put the fan on vibration dampers to dampen the movement transferred to the floor. And finally, we make sure the connection to the ducting system is flexible. This enables the fan to move freely without transferring its vibrations to the floor, bulkhead or ducting system. For more details, see image 6.

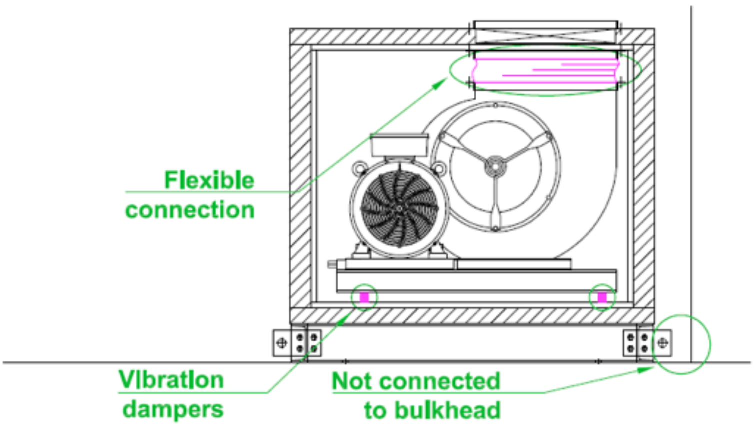


Image 6: Flexible arrangement of fan

CONCLUSION

The discussed solutions are typical for ventilation systems. But the same noise problems occur in other systems, like the drinking water system, where it's the circulation pump that's responsible for the vibrational & mechanical noise and water that creates turbulence in the pipes. Another example is a cooling plant, with freon lines and a compressor – mechanical parts, vibrations and flow.

There are many other possibilities to eliminate noise in your HVAC system. For example, turbulence can also appear when ducts and filters are dirty. The solution is always the same: reduce resistance. There are many ways to reach your goal. Think outside the box and focus on the source of the noise. If you know how it transfers soundwaves, you can find a way to block them. We summarise as follows:

MECHANICAL NOISE	
ORIGIN	Low frequency sound waves caused by mechanical parts such as a pump, fan or compressor.
SOLUTION	Isolate the source.

AIR FLOW NOISE	
ORIGIN	Turbulent and /or high speed medium in pipes and ducts.
SOLUTION	Reduce resistance.

VIBRATIONAL NOISE	
ORIGIN	Vibrations caused by moving objects, resonating through ducts, pipes, floors and bulkheads.
SOLUTION	Reduce resistance.

This concludes our whitepaper on noise control, written to highlight the importance of acoustic comfort in an HVAC system and give a better understanding of the nature of sound. We have seen that conditions like temperature and relative humidity are not the only parameters for a comfortable environment. By knowing the different types of noise, you can find a solution for every HVAC noise problem. If you still have any questions or a specific noise problem with your HVAC system, contact one of our technicians. We will be pleased to help you achieve acoustic comfort in your system.

SOURCES

Writing this white paper we have used the knowledge of our technical engineers who have based their findings on education and over 50 years' experience. Furthermore we have consulted the following sources:

- Khan academy: https://www.khanacademy.org/science/physics/mechanical-waves-and-sound
- Det Norske Veritas: Rules for classification of ships Part 6 chapter 3: Comfort class
- Van Cappellen consultancy: https://www.vancappellen.org/

"Sound comes in many different forms

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