THE SWEDISH SCHOOL OF TEXTILES
UNIVERSITY OF BORÅS

Acoustic Textiles

- The case of wall panels for home environment

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Abstract

Noise has become an increasing public health problem and has become serious environment pollution in our daily life. This indicates that it is in time to control and reduce noise from traffic and installations in homes and houses. Today a plethora of products are available for business, but none for the private market.

The project describes a start up of development of a sound absorbing wall panel for the private market. It will examine whether it is possible to make a wall panel that can lower the sound pressure level with 3 dB, or reach 0.3 s in reverberation time, in a normally furnished bedroom and still follow the demands of price and environmental awareness.

To start the project a limitation was made to use the textiles available per meter within the range of IKEA. The test were made according to applicable standards and calculation of reverberation time and sound pressure level using Sabine’s formula and a formula for sound pressure equals sound effect.

During the project, tests were made whether it was possible to achieve a sound classification C on a A-E grade scale according to ISO 11654, where A is the best, with only textiles or if a classic sound absorbing mineral wool had to be used. To reach a sound classification C, a weighted sound absorption coefficient (α_w) of 0.6 as a minimum must be reached. The project resulted in that it is technical possible to achieve a sound classification C with only textiles even though for this project another combination was chosen for proceeding with the calculations, because of account to price and environmental awareness. The calculations showed that it is possible to lower the reverberation time to 0.3 s in a normally furnished bedroom with 7 wall panels, and to achieve a lowering of the sound pressure level with 3dB with 7 wall panels.

This project showed promising results and leave openings for further research with only textiles and further calculations where more factors are taken under consideration to get more precise and reliable results.

Keywords: textile, sound absorption, reverberation time, sound pressure level

Sammanfattning

Buller och oljud har blivit ett ökande folkhälsoproblem och kan ses som en allvarlig störning i våra dagliga liv. Det är i hög tid att börja kontrollera och minska buller från trafik och installationer i hem och hus. Idag finns en uppsjö av ljuddämpandeprodukter för företag, men inga för den privata marknaden. Projektet beskriver en uppstart av utveckling av en ljudabsorberande väggpanel för den privata marknaden.

Projektet kommer att undersöka huruvida det är möjligt att tillverka en väggpanel som kan sänka ljudtrycksnivån med 3 dB, eller att få ner efterklangstiden till 0.3 s i ett normaldämpat sovrum och fortfarande följa de krav som satts vad det gäller pris och miljömedvetenhet.

Projektet genomförs i samarbete med IKEA of Sweden, då IKEA är en stor aktör på den privata marknaden. För att starta projektet gjordes en begränsning till att använda endast textilier på metervara som idag finns inom IKEA:s sortiment.

Testerna utfördes i enlighet med gällande standard och beräkningen av efterklangstid och ljudtrycksnivå med hjälp av Sabine's formel och en formel för ljudtryck = ljudeffekt.
Under projektets fortlöpande gjordes tester om huruvida det är möjligt att uppnå en ljudklassificering C på en A-E-gradig skala, där A är bäst, med bara textilier eller om en klassisk ljudabsorberande mineralull måste användas. För att nå en C-klassificering, krävs att en vägd ljudabsorptionsfaktor (α_w) på 0.6 uppnås som ett minimum.

Projektet resulterade i att det är tekniskt möjligt att uppnå en C-klassificering med bara textilier, men för detta projekt valdes en annan kombination för fortsatta beräkningar, med hänsyn till de pris- och miljömedvetenhets krav för det här projektet.
Beräkningarna visade att det är möjligt att sänka efterklangstiden till 0.3 s i ett normal möblerat sovrum med hjälp av 7 vägg paneler samt att uppnå en sänkning av ljudtrycksnivån med 3 dB.
Detta projekt visade lovande resultat och lämnar utrymme för vidare forskning med enbart textilier och ytterligare beräkningar där fler faktorer tas under övervägande för att få mer exakta och tillförlitliga resultat.

Nyckelord: textil, ljudabsorption, efterklangstid, ljudtrycksnivå

Popular scientific summary

Today noise which complicate communication, disturbing concentration and lowers the quality of life, could imply a health hazard if exposed to it for a longer period of time. Common reactions are headache, strong tiredness, tensions and body aches an also worrying, stomach ache, sleep disturbance and other stress related problems. There is also research showing connection between exposure to noise for a long time and high blood pressure, vascular spasm and heart attacks. This indicates that it is in due time to control and reduce noise from traffic and installations in homes and houses.

Today a plethora of products are available for business and open office spaces, but none for the private market. This project describes a start up of development of a sound absorbing wall panel for the private market.

To achieve sound absorption through traditional material used for this purpose is widely known, but the challenge lies within achieving sound absorption and still make it aesthetical pleasing and affordable to the many people.

In this project it was found that it is possible to attain a quiet and decent sound level in a bedroom with only textiles. Textiles have the advantage of being very versatile when it comes to properties, design and cost. This is promising in the matter of design for sound absorption in homes and to make it reachable for the many people. Though the sample which gave the good results with only textiles, involved both cotton and polyester fabric, both knitted and weaved, which means that it will probably end up in a too expensive product due to the different manufacturing processes and with the environmental aspect to it it is better to stick to one type of material in order to reduce the recycling process.

Though in this project, with the materials available within the delimitations, better results were attained with a polyester fabric together with a polyester batting, which also seems very promising since polyester can be recycled and produced from recycled material which gives it a interesting cost- and environmental aspect.

The result gives a promising good base to achieve design and sound absorption for everyday people who cannot afford to buy the traditional bulky ones mostly used for office spaces. The project also gives an indication of where to start for further research within this area.

Preface

This project is written as a final thesis in Bachelor of Science in Engineering in Textile Technology at the Swedish School of Textiles, Borås. The idea for this project started a year ago when my neighbours woke me up every morning way too early. I live in a small apartment in an old house and the walls are very thin which means a lot of sounds are coming through and can be very disturbing.
I realized that there were no sound absorbing products available for the private market and at the time I was working at an IKEA store in Gothenburg, so the connection between IKEA and sound absorbing products became clear.
When time came for writing my thesis, what I wanted to write about were clear. Through contacts at the IKEA store, I worked my way through the company to find the right person. Eventually I got in contact with Charlotta Walse and the textile department at IoS, IKEA of Sweden, in Älmhult. Fortunately they could provide me with a supervisor, Marius Lehadus who could help me with my thesis and this project.

To make this project possible I needed help from someone who knows how acoustics works and also understands the different properties of textiles. For this a warm special thank you to Karl Tillberg, with his brilliant knowledge of acoustics, valuable input and interesting discussions, and also for his patience with me when it comes to learning new programs, calculations and supervising me through the world of acoustics.
A warm thank you to Marius Lehadus and Charlotta Walse at IKEA of Sweden for their contribution and commitment in my project and to Marius special thank you for taking such good care of me when visiting Älmhult and IKEA of Sweden.
For valuable tips and good advice about the writing and the academic part and also for pushing for me to get help from someone who really knows acoustics, a great thank you to Nils-Krister Persson at The Swedish School of Textiles.
At last but not least, also a great thank you to IKEA Kållered and all the personnel, especially Inger Olson who provided me with a work space and at last but definitely not least, the personnel at IKEA Business, for lending me an office space and putting up with me and keeping me company during this project.

All of you have in different ways contributed to this project, a warm thank you to all!

/ Louise Wintzell

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1 Background

In the world today there are a lot of different health concerns; one of them is noise disturbance. Noise which complicate communication, disturbing concentration and lowers the quality of life could imply a health hazard if exposed to it for a longer period of time. Common reactions are headache, strong tiredness, tensions and body aches. Also worrying, stomach ache, sleep disturbance and other stress related problems. There are also research showing connection between exposure to noise for a long time and high blood pressure, vascular spasm and heartattacks (HRF 2009).

According to the *World Health Organization's Guidelines for Community Noise*, the noise has become an increasing public health problem and has become serious environment pollution in our daily life. This indicates that it is in time to control and reduce noise from traffic, factories in offices and in homes and houses (Ching-Wen, L. et al (2005).

In order to alleviate this problem certain actions can be taken. One of those actions could be to take under consideration how the environment is decorated, regardless if it's an open office space or a noisy apartment there are products available to dampen and optimise the sound perception in a room.

On the market today there are several products available in this area, but none or very few, for the private market. For a private person these products are far too expensive. That is where IKEA comes in, they can provide private persons with all types of furniture and home decorations, but today there are no such products as a sound absorbing wall panel available within their range.

There is also an environmental aspect to this type of products, with a lot of waste from the nonwoven industry, which sound absorbing products usually are made of, the waste is a large and growing issue.

1.1 Inspiration

The inspiration for this project came about a year ago when Karl Tillberg held a lecture about acoustics and textiles at the Swedish school of Textiles for the students at the Textile Engineering program. Karl spoke about sound absorption in textiles and connected it with interior and perception.

Some apartments of today are not very well isolated and can be very responsive. For small apartments where the walls are very thin, neighbours could easily be heard when they are talking and when children are cranky. Also the sound from the street outside with all the traffic and busses could be very disturbing and a big problem.

On the market today there are several products available for this matter, but they are all directed against companies and open office spaces and are therefore quite expensive, which also will be discussed in the situational analysis. In order to make a difference in attaining an optimized sound level a lot of factors play a role. It depends on what type of furniture there are and how much the room is furnished with, if a lot of absorbing materials, like textiles for instance, are used in the room as curtains, carpets cushions and blankets. Also the size of the room, ceiling height and even the shape of the room make a difference. The type of material the building is built with and the isolating material, how big the windows are and so on are fundamental aspects when it comes to insulating and sound absorption.

With this in mind and listening to Karl it became more and more clear that there should be such a product available for the many people to use in their homes. The product should be able to lower the sound level in the room for unwanted noise and to do so without being as expensive as the products available at the public market today.
With good knowledge of the IKEA range and interest in interior design the connection between IKEA and sound absorbing products became clear.

1.2 Situational analysis

From surveys among IKEAs' customer, the result showed that noise is a big issue and also that products that insulate and could help the customer save energy, was of growing interest. From this a draft was made to take the customers opinion under consideration and a project was started to seize this knowledge. So when the idea about sound absorbing products for the many people came up, it was most welcome.

Today at IKEA there are several traditional furnishing products available that have sound absorbing properties, as sofas beds and so on, since almost all products with textiles or some sort of absorbing material have sound dampening properties. However, none of them, except for three curtains, WERNA, LENDA and MERETE are marked as having sound absorbing properties, help to reduce the noise. No products are marketed as noise reductive even though surveys show that this is one of the properties that the customers are asking for.

IKEA Business, is a department of the IKEA warehouses today which provides businesses with furniture and interior design. Whether they just want to buy a new chair or decorate a whole new office space, IKEA Business can provide that (ikea.com). Even though IKEA says that they can decorate your whole office space, it is not entirely true. Within the range GALANT, which is one of the series used for furnish and decorate offices today, there is a hatch when it comes to sound absorbing products. Today IKEA can provide only one type of screen to put on your office desk, and it's more of a sound blocker than a sound absorber. This doesn't have any sound classification and is therefore hard to compare to the ones that are on the market today. This screen is not build up of traditional sound absorbing materials, even though it has some sound absorbing properties. The size of this product is 1600·640·50 mm, and the frame is made of solid spruce, particleboard and fibreboard. The fabric used is a 100% polyester composition (ikea.com). When this screen is not enough, IKEA Business refers to Zilenzio, a company that provides sound absorbing products. Zilenzio is a Swedish company that earlier had an agreement with IKEA when it came to sound absorbing screens. Their vision is to achieve a balanced sound environment for every office (zilenzio.se).

When in contact with Zilenzio a example was set up regarding how many sound absorbing wall panels would be needed to achieve the perfect sound conditions in a normally furnished living room of about $40m^2$. Perfect sound condition means that the sound pressure level is optimised for the specific room and the purpose for that room.
To a normally furnished living room belong a sofa, carpet, curtains and so on. According to Zilenzio's calculations, six to seven sound absorbing wall panels of 1000·1000·50 mm would be needed to attain optimised perceiving of the sound. One of the wall panels with a price range 1 fabric, which means 100% Polypropylene, $220g/m^2$, would cost 2500 Swedish kronor, VAT excluded.

1.3 Aim

The aim for this thesis project is to find out if it's possible to attain a quiet bedroom with a lot of disturbing noise by only using textiles. Most people want to have a quiet and calm environment when they are about to sleep so therefore the focus will be on bedrooms for this project. A quiet bedroom is according to the Swedish guidelines for building buildings, BBR, when building new building or renovating, the sound pressure level must not reach a higher level of sound pressure than 30 dB. Also to see if it possible to manufacture a sound absorbing wall panel, good enough to decrease the sound pressure level in a normally dampened room with 3 dB.
The aim is also to see if enough sound absorption can be achieved with only textiles.
The price for the product should be low enough so that a regular person can afford it. Also the environment should be taken under consideration, since according to the author of this thesis, all product development should have the environment as a parameter for new products. Therefore use as little material as possible but still be able to reach a sound absorption level C, and if it's possible make a product that can be recycled or produced from recycled material.

1.3.1 Question at issue

In this work the main question is:

- Is it possible to manufacture a sound absorbing wall panel, for homes?

More specifically:

- Could the sound level in a room be decreased by 3dB?
- Could the reverberation time be decreased to 0.3s?
- Is it possible to attain a sound classification C by only using textiles?
- Meanwhile maintaining a low product price and environmental awareness?

A wall panel referrers to a sound absorbing panel to hang on walls, made from textiles and some sort of batting material. A living environment for the many people is what homes referrers to. The room dimensions are: 3· 4 ·2,5 m. Low price is the same as affordable for the customer of IKEA. Environmental awareness means in this project to take under consideration the whole life cycle of the product, which will be return to for further discussion during this work. Sound classification C means a classification of sound conditions according to standard which will be returned to in chapter 2.3.2 for deeper discussion. Why the values of 0,3 s and 3 dB are chosen will be explained in chapter 2.3. and 2.3.3.

1.3.2 Delimitations

Delimitation to this project has been done to focus on bedrooms and that since most people find it important to have a quiet environment in their bedrooms. A limitation will be done to one type of sound absorbing textile product that will be interesting and a conclusion was reached to focus on wall panels. Hence wall panels are built up in a quite simple way and are easy to compare to the ones on the market today. Also because it hangs on the wall, which doesn't need further floor area, considering the size of a regular bedroom.

A limitation will also be done to just take under consideration stationary sounds as noise from ventilations for example. Limitations to not look at low frequencies, as the area from 0 –

200Hz, will also be done since it is very difficult to control these frequencies with a thin wall panel.

Limitations in which material to used have to be done since the price cannot be too high and with the environment in mind as little material as possible should be used and preferably recyclable or produced from recyclable material. To simplify this project a bit a limitation was made to use existing textiles available in buying per meter within the range of IKEA today and limited access to batting or other absorbing materials was also a restriction. Further a limitation according price calculation of a finished product was also done due to less importance in this stage of developing this type of product.
A limitation to not consider energy consumption for producing different types of nonwoven materials will also be done since the focus in first hand will be on sound absorption.

2. Acoustics

2.1 Introduction

Predominantly humans are considered to perceive their environment through their visual sense. When it comes to interaction communication, it is audition and not vision, which is the most important and relevant social sense of the human being as a communication organ (Blauert, J. 2005).

One cannot close the ears by reflexes like the eyes can, for example it is much more easy to educate blind people than deaf people. The hearing extends to areas all around the listener while the visual sight is limited to a certain view and also it is still possible to hear in darkness and through optical barriers (Blauert, J. & Xiang, N. 2009).

Acoustics is the science of sound and of its additional auditory events. The term acoustics originally comes from the Greek ακουστός, and means “to hear” or “to make oneself heard” (Blauert, J. & Xiang, N. 2009). An auditory event is something that becomes actual in the act of hearing and sound is mechanic vibrations, mechanic waves, in elastic media. An auditory event don’t happen without sound being present, except for when it comes to tinnitus. When the frequency of sound is not within the range of hearing, or for deaf people, there can be no auditory event even in the presence of sound (Blauert, J. & Xiang, N. 2009).

2.2 Acoustic terms

Sound wave is a pressure wave motion in the air that the ear detects and perceives as sound (ne.se). By definition sound is a wave motion in an elastic media and the elastic media could be the air, water or a rock. The sound wave delivers energy to the media and the energy is carried away by the sound wave. A sound wave could also be described as a sound wave occur when a vibrating body sets the surrounding air in fluctuations and variation in air pressure appears (Highfield, D. 2000). A sound source oscillates and brings the surrounding air into motion and in the presence of a recipient the sound can be perceived (Möser, M. 2009). These motions in air pressure perceives as sound and the sound can be affected by different objects. How hard objects, for instance, affect sound, depends on how big the object is compared to the wavelength by the current sound. High frequencies with a short wavelength acts in the same way as light does. The sound reflects by the surface of the hard object like a mirror. This phenomenon can also be likened with the small water waves from a small rock thrown in the water, when they hit an obstacle. Sound waves with long wavelength will pass an obstacle largely unaffected, in the same way as when waves from a motorboat surge hit the bridge pole. This is one of the reasons that a traffic noise protection shield dampens high frequencies much better that low frequencies (Åkerlöf, L. 2001).

When it comes to sound there are two attributes to take under consideration, tone and loudness. The physical amount for loudness is sound pressure, and for tone it is frequency (Möser, M. 2009). Frequency is the repeated events within a given time interval and it’s measured in Hertz (Hz). 1 Hz means that one event repeats once per second (Gallagher, M. 2008). The range of frequency in a technical aspect covers more than the range that is audible by the human ear, the hearing level. For the human ear the hearing range starts about 16 Hz and goes up to about 20 000 Hz and the range in which the human hearing is most sensitive is within 1000 – 3000 Hz (Highfiled, D. 2000).

The human ear is not equally sensitive to all frequencies, the perception of sound depends on sound pressure level, the objective strength and also on a complicated manner of the spectral composition of sound signal, duration and other factors (Highfiled, D. 2000). Below the range of audible sound to the human ear, the frequency range is called the infrasound (Møller, H. & Pedersen, C.S. 2004). The infrasound is more relevant when dealing with vibration control of machinery and structures for example. Above the hearing range is the ultrasound, which is used in applications as medical diagnosis (Möser, M. 2009). The human voice lies within 500-4000 Hz and the human hearing is most receptive to sounds within that range (Zetterblom 2011). Sounds can be divided into categories in terms of frequency, which are shown in table I.

Table I. Categories of frequency. Reference: Blauert, Jens. & Xiang, Ning (2009).

Sound	Frequency, Hertz (Hz)
Audible sound	16 Hz - 16 kHz
Ultrasound	> 16 kHz
Infrasound	< 16 Hz
Hypersound	> 1 GHz

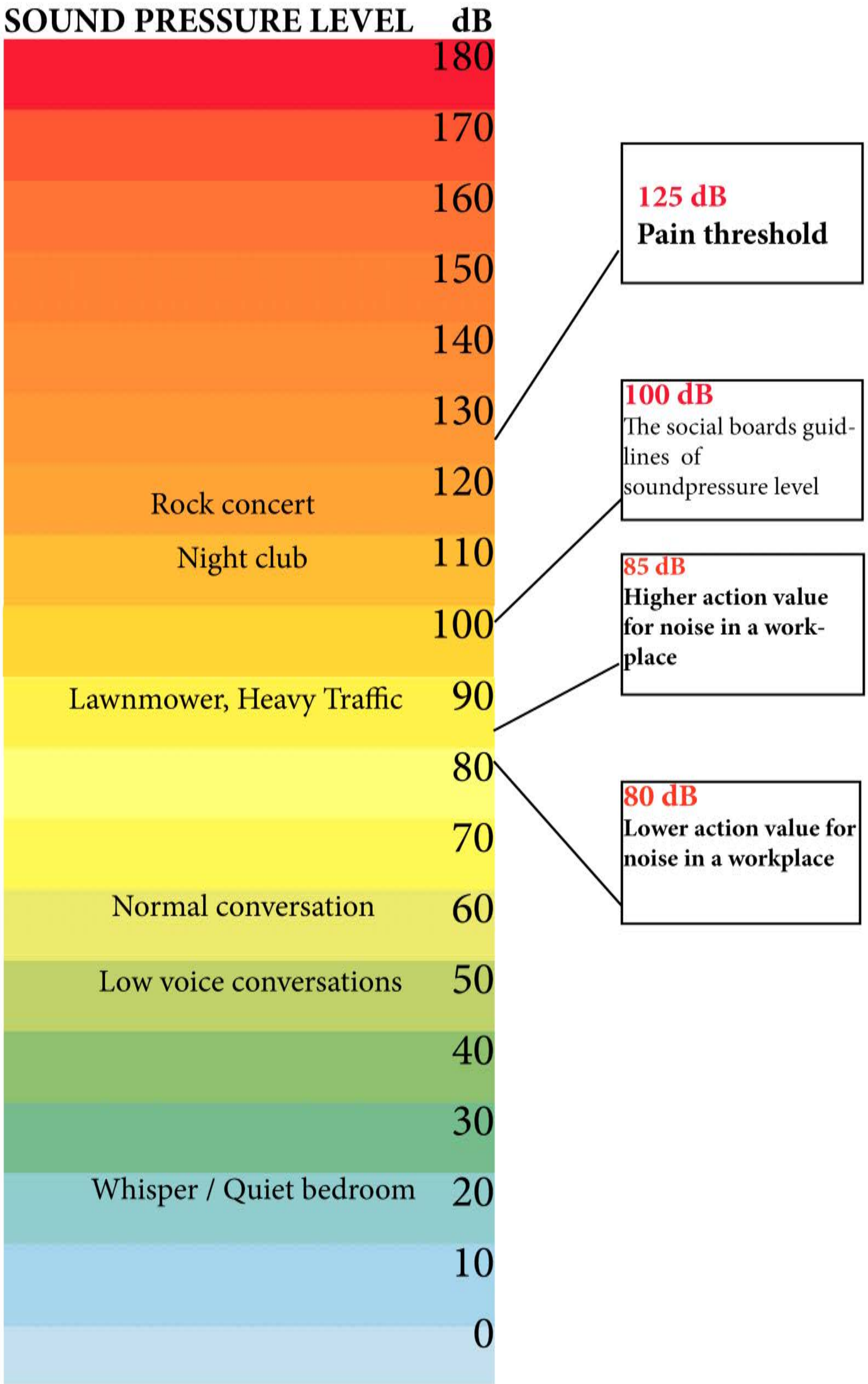
2.2.1 Decibel

Different sounds have different intensity. To be able to measure the intensity relatively the scientific unit decibel (dB) is used, and the easiest way to describe it is the volume of sound, the sound pressure. The sound pressure is the difference between the instantaneous pressure and the static pressure (Highield, D. 2000). The concept of decibel is logarithmic, and the scale is designed according to the capacity of the human hearing of sensing sound pressure. The pressure of sound sinks with increasing distance from the source of the sound (Streitberger, E. 1991).

How we perceive sound is very individual, some people have a pain threshold at 120-130 dB, but if you are sensible to sound or have an impaired hearing you have a limit at 40-50 dB. What also plays a role is how long one is exposed to the sound. If exposed to 100 dB for fifteen minutes it has the same effect as if one is exposed to 85 dB for eight hours (HRF 2009).

In Figure I some examples of sound are shown and to what dB level they correspond.

Figure I. Examples of sound are shown and to what dB level they correspond. *Reference: HRF 2009 and Åkerlöf, L 2001. (Wintzell 2013)*



2.2.2 When a sound wave hit a surface

When a sound wave hits a surface it reflects in some way. How and how much depend on the surface, if the hitting surface is large enough and very different properties from the sound wave, it reflects (Tillberg 2012). Imagine it like light towards a mirror, it reflects the whole light wave and the same happens with the sound wave.
Though if the surface is porous or is giving in for the sound wave, the air pressure attains losses of reflection, so called sound absorption. Absorption of sound waves is a process where the acoustic energy is transformed in to a different form of energy.
The sound can also be spread with an diffuser and the main difference between reflectors, diffusers and absorbers is that an absorber removes sound energy, which doesn't happen with reflection and diffusion (Kleiner, M. 2003).

There are a variety of ways to reduce noise today and they can basically be grouped by passive and active mediums. Passive mediums which is the most common one used for sound absorption, reduces noise by disseminating energy into heat, a typical passive medium is a porous material (Yanping, L. & Hong, H. 2010). All absorbing materials have a level of porosity. A porous material is a material containing pores or voids. The sound can be absorbed in a porous material, and it can be explained as sound waves bouncing off the walls inside the voids in the porous material until they have lost their energy, they are absorbed. This means that the sound wave are weakened through a "internal heat conduction" (Highfiled, D. 2000).

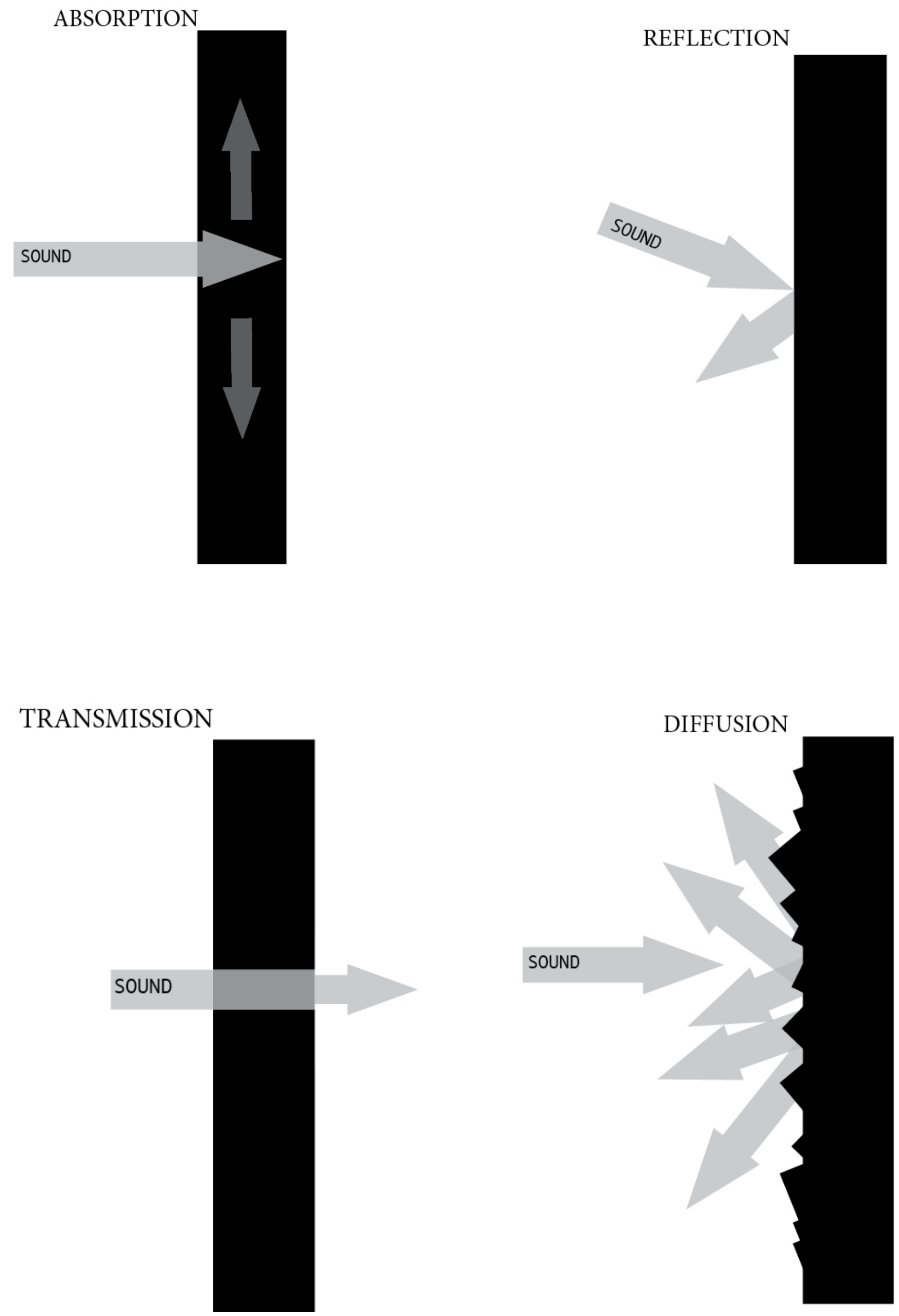
The level of sound absorption varies with the frequency (Åkerlöf, L. 2001) and therefore acoustic materials differ with acoustic properties depending on acoustic impedance of the material (Tillberg 2012), since the impedance differ at different frequencies (White, G.D., Loui, G. J. 2005). A challenge when it comes to impedance matching is that it is often dependent on frequency and therefore difficult to get an absorber, which covers the whole frequency range. To work as an absorber the acoustic impedance in the material should have similar impedance as the surrounding air (Tillberg 2012).

The sound can also be reflected. Reflection of sound is when the sound wave hits a surface that is hard and compact with acoustic impedance that is very different from the sound wave and the sound are reflected into a certain direction (Tillberg 2012). A reflector is an acoustical device that has the ability to provide a surface that redirects the sound wave in another angle without any energy loss (Gallagher, M. 2008).

When the sound wave hits a surface that is uneven or convex which means that the sound waves are spread in different directions, it's called diffusion. This is a process which reduces the intensity of the reflection when breaking a single reflection into many smaller and scattering them into different directions. A diffuser can help reducing the problem with acoustic interference (Gallagher, M. 2008).

When a material has similar impedance as air, the sound wave will transmit into the material (Tillberg 2012). There are different types of transmission of sound. Direct sound transmission means that the sound on one side of the wall puts the wall in oscillation and the wall radiates sound out on the other side. Flanking transmission happens in the same way but the radiance goes through other parts of the building than the partition wall. Over hearing means the transmission between room via installations such as ventilation, radiators etc an there is also leakage, which is referred to as the transmission between rooms via unevenness in the wall, holes and slots for example where a floor structure meets the wall (Åkerlöf, L. 2001). In figure II an explanation of these different terms are shown.

Figure II. A clarification of absorption, reflection, transmission and diffusion.



2.2.3 Perception

How we perceive different types of sound could differ from one person to another. The acoustic structure of the human voice contains information of the speaker's emotional state and identity. It's remarkable what accuracy and simplicity this is perceived, by other humans. (Belin, P., et al. 2000). Although according to *Hörselskadades riksförbund* (HRF 2009) surveys show that when other people are talking in the background is perceived as the most disturbing sound because of the fact that speech is a type of sound that our brains automatically perceives as important. Therefore it's more difficult to filtrate speech than other types of noise. It becomes even more difficult to perceive a person's voice when other conversations are ongoing at the same time. These sounds have the same characters of sound and are therefore difficult to distinguish (HRF 2009).

How humans perceive low-frequency sound, below 200Hz, is important since it contains a significant amount of energy and much of the sound we are exposed to in our everyday lives comes within this range. The perception of sound and also the sensitivity to sound changes with decreasing frequency (Møller, H. & Pedersen, C.S. 2004).

The expectation of sound also effects how we perceive the acoustics. In the library for instance, the expectations are that it should be quiet and calm with short reverberation time, but in a church you expect it to be long and with little absorption even though the speech would be perceived better if there was a bigger absorption in the room (HRF 2009). There is not only negative perception of sound, there is also a lot of positive sounds that could help to increase health, and make us calm and feel happy, like music and birds singing (Åkerlöf, L. 2001).

2.3 Room acoustics

Usually the purpose of room acoustic actions are to dampen unwanted sounds with absorbing materials or to create good conditions for wanted sounds with help of reflectors, diffusers and calculating reverberation time and considering the shape of the room. What is considered "good room acoustics" varies with a lot of different factors. It depends on what the room is used for, the size of the room, the expectations of the acoustic in the room in order to optimise the spread and absorption of the sound.

The demands of the acoustic in buildings, varies a lot from rooms used for music compared to rooms used for speech. The demands of how long the reverberation time, which will be explained later in this chapter, should be depend on the shape and the size of the room and what it should be used for. The demands are not as extensive for smaller rooms as for larger spaces.

According to the Swedish guidelines for how to build buildings, *"Boverkets Byggregler " BFS 1998:38 "7 Bullerskydd, 7:2 Bostäder"*, which from now on will be referred to as BBR, there are some requirements to be followed when it comes to sound levels. Sound level indoor from installations such as ventilation, should have a sound pressure level of maximum 30 dB in bedrooms and rooms used for education from sounds with long duration, and 35 dB for sounds with short duration. The sound pressure level indoor from traffic noise is 30 dB in classrooms and rooms used for resting, and also in rooms used for resting and sleeping shouldn't have a sound pressure level above 45 dB between 10 pm – 06 am more than maximum five times per night (Åkerlöf, L. 2001).

Compared to a kitchen which doesn't have as high requirements for sound pressure level as bedrooms the maximum limit is set to 40 dB. Due to the fact that kitchens have a lot more hard reflective areas and usually kitchens have more of the hard unwanted sounds (Åkerlöf, L. 2001).

According to standard SS 25268:2007, sound classifications are used to define the noise conditions in a room. Sound classification A implies very good sound conditions. It's considered suitable for spaces used for activities and businesses where audibility is prioritised. Class B is a minimum requirement for living environment. It's much better than C, but could still be a bit disturbing for comprehending of speech to people with impaired hearing. Class A and B is chosen if particularly good sound conditions are used (ISO 25267:2004/T1:2009). Class C is satisfying sound conditions for a majority (ISO 25267:2004/T1:2009) of the living and represents minimum requirements for Swedish buildings according to BBR (BBR,2008). Class D is only for exceptions when Class C for some reason cannot be fulfilled, often related to rebuilding or if it's a really old building that cannot be rebuilt in such a way that Class C can be achieved (Åkerlöf, L 2001)/(ISO 25267:2004/T1:2009).

To achieve a sound classification C for a bedroom, the sound pressure level should not exceed 30 dBA equivalent level and not reach higher than 35 dBA as a maximum for sounds with short duration. With equivalent level means the sound pressure level under a long period of time. When focus on disturbing sound from ventilation or traffic noise from a larger route, it's the equivalent level that is interesting which means 30 dBA (ISO 25267:2004/T1:2009). The sound pressure levels in kitchens are according to standard ISO 25267 set to 35 dBA and 40 dB wich is a higher limit than for rooms used for resting.

There is also an aspect to consider when it comes to insulation of the building and how it hinders the noise to spread from one space to another, that's referred to airborne sound insulation. With airborne sound insulation one mean the measurement of how much the building construction can hinder sound within one space to propagate into another. The insulation depends on the properties of the materials of which the separating surface of the wall are made of (Åkerlöf, L. 2001).

When talking about sound waves, the larger the amplitude is, the stronger we perceive the sound. A loud tone has higher amplitude than a weaker tone, but could have the same frequency. Some frequencies are perceived stronger by the human hearing than others therefore we could hear two sounds with different frequencies, but the same amplitude and still perceive one stronger than the other (Zetterblom 2011).

When measuring frequencies as will be discussed later in this chapter, one need to analyse the data. Analysing by a frequency basis could be very time consuming and impractical. Therefore scales of one-third octave bands and octave bands have been developed. The whole frequency range have been divided into set of frequencies, so called bands. Each band includes a specific range of frequencies. This band is called an octave and one octave is every eight tone up or down in a diatonic scale (Nationalencyklopedin 2013).

2.3.1 Frequency analysis

In order to get the information that is necessary to make a classification of a room or a specific product, one need the practical sound absorption coefficient. That is a frequency-dependent value, based on measurements in one third octave band according to ISO 354:2003, which have been recalculated to octave bands according the same standard (ISO 11654:1997). When calculated, this is a weighted absorption coefficient and is a frequency dependent summary value, equal to the value of the reference curve, which will be explained later in this chapter, read by 500 Hz, after this has been adapted according to ISO 11654:1997.

To get these values a frequency analysis has to be done. That is an analysis of the signals distribution over the frequency axis. Traditionally the analysis is done mathematically or with help from analogue electrical filter, built up by conventional electrical components. Today two methods are used with digital technique, Fast Fourier Transform FFT, and digital filtering. Both methods use digitalised measuring values. Every filter type, are named after its effect on the signals frequency spectrum band (Bodén et al. 2001).
An band pass filter that is ideal only lets through the frequencies that are within the bandwidth. But in fact the flanks of the bandwidth have a certain inclination, which means that frequency components just outside the pass band don't dampens completely. A common way to define the upper and the lower frequency limits is to specify the frequencies by which the signal is dampened by 3 dB.
Filters with bandwidth, which is proportional to the current centre frequency is called Constant Relative Bandwidth filter, CRB-filter. This is also called one-third octave band-filter. The centre frequencies are standardized and are named with band numbers according to their centre frequencies. Every octave band comprises three one-third octave band (Bodén et al. 2001). It's the values in octave band that later will be adjusted according to the reference curve.

2.3.2 Sound Classification

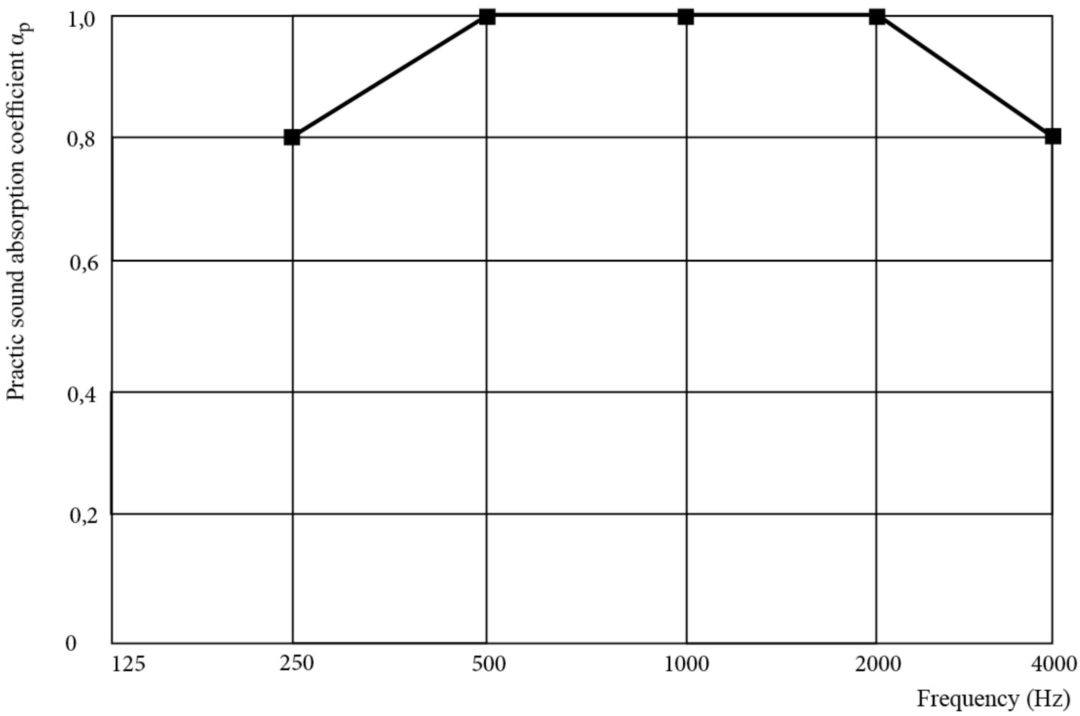
According to international standard ISO 11654:1997, specification of a method where the frequency dependent sound absorption can be recalculated into a summary value are described. This summary value can lead to a classification of sound class, in order to compare different types of sound absorbers when it comes to acoustical properties and demands. Before this can be done the one-third octave band measurements are converted into octave band according to standard ISO 354:2003 (ISO 11654:1997). To get the value for what sound class the tested object belongs to it has to be compared to a weighting curve. The weighting curve will from here on be referred to as the reference curve. The reference curve starts at 0.8 at 250 Hz and goes up to 1.0 for 500, 1000 and 2000 Hz, and at 4000 Hz it goes down to 0.8 again which is shown in table II.

Table II Reference: EN ISO 11654

Frequency	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
Value	0,8	1,00	1,00	1,00	0,90

In order to get the reference curve right, it lowers by 0.05 on the value axis per step, until the difference between the reference curve and the added values on the current curve are no more than 0.1. It is only the negative difference that counts. Once the reference curve is in place the value is read by 500 Hz. The value attained is the practical sound absorption coefficient and is compared to a diagram in the standard ISO 11654:1997(ISO 11654:1997). In figure III a diagram with the starting point of the reference curve are shown.

Figure III. A graph showing the starting point of the reference curve. Reference: ISO 11654:1997 (Wintzell 2013)

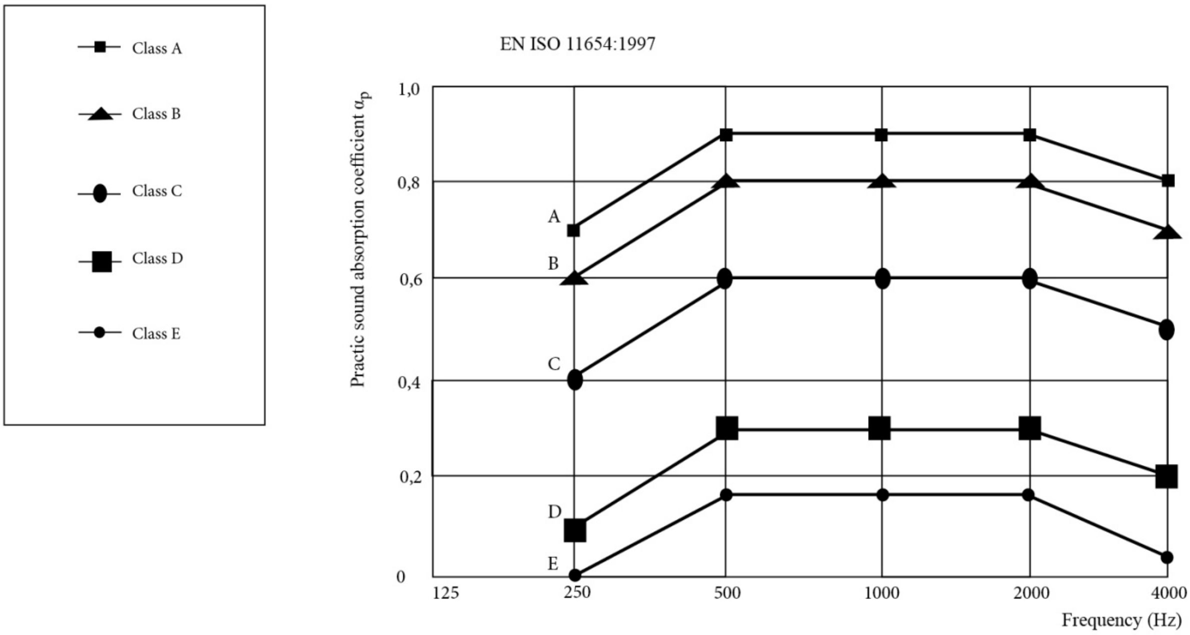


After lowering the reference curve into the right position and then reading it by 500 Hz, a weighted sound absorption coefficient are attained. This value can be compared to a table of sound absorption classes. In table III the different classes and their interval are shown and in figure IV the graphs of the different classes are shown.

Table III. Sound absorption class and each absorption coefficient value. Reference: ISO 11654:1997

Sound absorption class	α_w
A	0.90; 0.95; 1.00
B	0.80; 0.85
C	0.60; 0.65; 0.70; 0.75
D	0.30; 0.35; 0.40; 0.45; 0.50; 055
E	0.15; 0.20; 0.25
F	0.00; 0.05; 0.10

Figure IV. Each sound class interval in graphic form. Reference: ISO 11654:1997 (Wintzell 2013)



2.3.3 Reverberation time

Reverberation time is the measurement of how long time the sound bounces in a room. Everything in a room as walls, ceiling, furniture and so on works as a "sound mirror" which means that the sound reflects against these areas and propagates as echoes in the room (HRF 2009). The real definition of reverberation time is according to a international standard:

"Time, in seconds, that would be required for the sound pressure level to decrease by 60 dB after the sound source has stopped"

(ISO 354:2003)

Imagine a room as a big container filled with water. The water supply pipe fills the container with water in the same way as the sound source fills the room with acoustic energy until a certain balance is reached. The level of balance, whether it is water or sound, can be explained by a compensation of the inflow by the out flow, while the water, or sound, exiting through the leaks in the container. That can be explained likened to energy loss through sound absorption in the room. If the water supply pipe turns off the water level will sink, and the same will happen with the sound. If the sound source is turned off, the acoustic energy flows out (Möser, M. 2009). To hear a reverberation one has to be in an enclosed room with a sound source being turned off at the time one is present in the room. The duration time depends on the volume of the room, but also how it's decorated, the shape of the room and how many and large absorbing areas or surfaces the room has (Heylighen, A et al 2010).

If the volume is large and with little absorption the reverberation time can continue for a long time and easily extend to a couple of seconds. The sound waves are reflected several times at the walls with different angles and can under two seconds travel as far as 700 meter (Möser, M. 2009).

When it comes to designing a room with account to optimise the acoustics there is often boundaries and sometimes problems with the reflections of the sound. This sort of design objectives can be prevented and solved through implementing absorbent structures in the ceilings and in the construction of the walls with properties that are suitable for the purpose (Möser, M. 2009). Optimal reverberation time for offices is according to the author of "*Byggnadsakustik*" ca 0.5-0.6 s per a room of up to 30 m^3. For rooms of up to 50 m^3 it's up to 0.7 s in reverberation time (Åkerlöf, L 2001). This is for an office space, which doesn't have the same demands on having a quiet environment so the reverberation time in a bedroom should be lower than 0.5 s.

For calculating reverberation time for simpler theoretical models, the most traditional method is with Sabine's formula. Wallace Clement Sabine was a Harvard assistant professor that made measurements of acoustics in Harvard University halls. His conclusion was that reverberation time was the most important parameter when it comes to acoustics (Beranek, L. 20011).

The formula assumes that sound energy diffuses equally through a room but in fact, since the large areas in a room are characterized by some absorption these conditions are rarely met (Passero, C.R.M. & Zannin, P.H.T. 2010). In a diffuse sound field of ideal measurements, the acoustic intensity comes from all directions and thereby has identical energy in all positions. This would mean identical experience of the sound in all positions in the room. This ideal situation rarely occurs since the sources of sounds often are non-stationary(Tillberg 2012). Although in a concert hall, the reverberation time influences the sound in several ways and is nearly the same in all seats and this is where Sabine was active.

Another factor that plays a role is the fact that there is also a direct sound field. The direct sound field could be someone speaking or a loudspeaker with music and where no obstacles are in the way between the source and the receiver (Tillberg 2012).

Calculation with Sabine's formula are based on diffuse sound field and that the absorption area is assumed spread evenly on all surfaces in the room. Depending on what type of material is used, the diffuse sound field could differ from normal incidence. If you have a textile fabric for instance, which is not a homogenous material, it acts different in different angles. If the sound comes perpendicularly into the fabric, the fabric has one type of properties, but if the sound comes at another angle into the fabric it has other properties. To control these reflections and to create good sound conditions absorbers, diffusers and reflectors are used (Tillberg, K. 2012).

Sabine's formula is given:

$$T_R = 0.16\ VA + 4mV$$

T_R is reverberation time.

V is the volume of the room.
A is the sum of absorption area
$4mV$ corresponds to sound absorption by air, where V is the volume of the room and m is the absorption coefficient of air. The result is expressed in Sabine's/m (Passero,C.R.M. & Zannin, P.H.T. 2010). In these calculations the sound absorption of air is not taken under consideration. This gives:

$$T_R = 0.16\ VA$$

2.3.4 Direct sound field and reverberation sound field

To analyse stationary sound filed, which comes from one source in a room, means that the frequency spectrum don't change with time. The sound field can be divided into two parts, direct sound field and reverberation sound field. Direct sound field referrers to those sound waves that just left the sound source and not yet have reflected towards a surface and reverberation sound field referrers to those of the sound waves that have reflected towards a surface one or more times towards different surfaces. There is a correlation between sound effect and sound pressure and the correlation depends on the dampening in the room. It also depends on directs sound which varies depending on how far away from the sound source one are. In this project limitations have been done to only use the reverberations sound field.

Sound pressure = Sound effect

$$L_p = L_w + 10 \log \frac{B}{4\pi^2} + \frac{4}{A'}$$

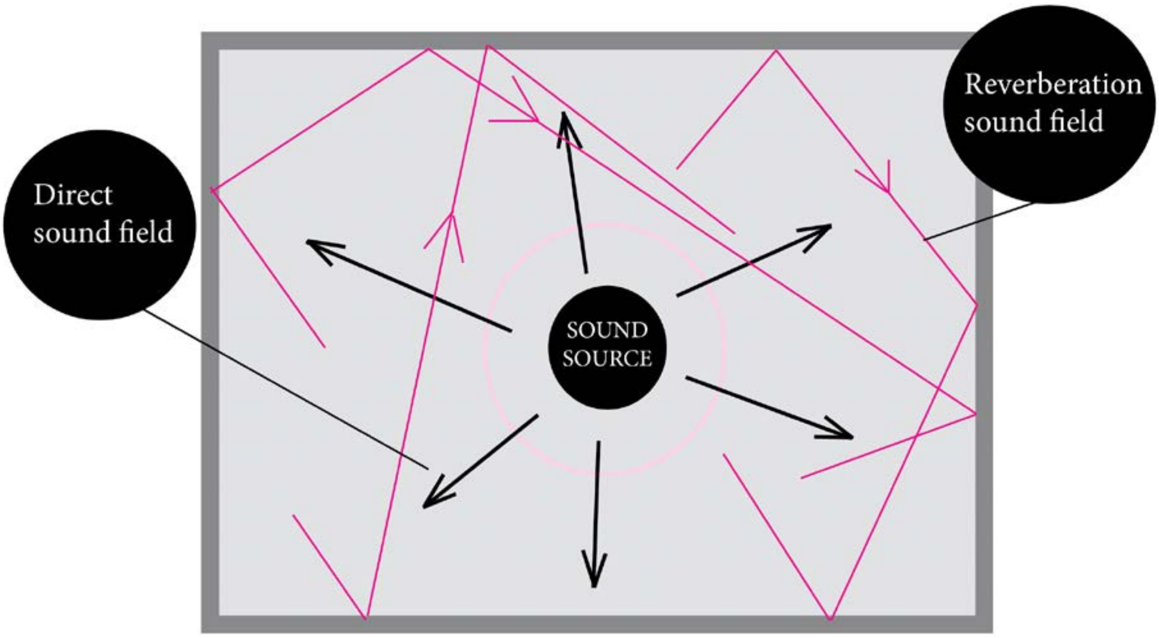
Where $A' = \frac{\langle\alpha_d\rangle S}{(1-\langle\alpha_d\rangle)}$

For practical applications of the formula above, usually A' is interpreted as the equivalent absorption area A which means that the factor $(1 - \langle\alpha_d\rangle)$ has been neglected. In context with Sabine's theory this is considered relevant since the impact of this factor on A is proportional with $\langle\alpha_d\rangle^2$ which can be considered negligible in the area where the theory is valid i.e. $\langle\alpha_d\rangle \leq 0.3$. Since we are not taking into account the direct sound $\left(\frac{B}{4\pi^2}\right)$ this factor is also neglected (Bodén, et al. 2001). This leaves the formula to:

$$L_p = L_w + 10log\left(\frac{4}{A}\right)$$

In figure V a simplified picture of direct and reverberation sound field are shown.

Figure V. A simplified picture of direct and reverberation sound field. *Reference: Bodén, et al. 2001 (Wintzell 2013)*



3. Textiles

A textile is a material with components from natural or manufactured fibres or even a blend of those two. The fibres are spun into yarn and then formed into a textile fabric in several different ways as through either knitted, weaved or joined together by felt making or stitch bonding (Humphries, M. 2009).

According to the British National Encyclopaedia;

”Textile, any filament, fibre, or yarn that can be made into fabric or cloth, and the resulting material itself. The term is derived from the Latin textilis and the French texere, meaning “to weave,” and it originally referred only to woven fabrics. It has, however, come to include fabrics produced by other methods. Thus, threads, cords, ropes, braids, lace, embroidery, nets, and fabrics made by weaving, knitting, bonding, felting, or tufting are textiles. Some definitions of the term textile would also include those products obtained by the papermaking principle that have many of the properties associated with conventional fabrics.”

(Encyclopaedia Britannica 2013)

The definition of a textile is difficult since the material can be used for so many different areas. For this thesis a textile is defined as any material made of intertwine fibres.

A textile material usually has low density which could be of disadvantage when it comes to sound diffusion. A textile is either acoustic absorbing or acoustic transparent. It’s not air tight or satisfactorily stiff but by designing complex 3D structures stiffness can be attained at a level where it can acceptably diffuse medium to high frequencies. The same goes for absorption, it all depends on what region of frequency that is of interest. When it comes to diffusion, textile materials could be of advantage since it could be designed in an aesthetically pleasing way (Tillberg, K. 2012). The acoustic properties of textiles differ depending on how the textile is built up, through knitting or weaving or other techniques. In the structure of textiles small air pockets are formed and could affect the acoustic properties (Moholkar, V.S. & Marijn, M. C. W. 2003).

Textiles are also highly attractive when it comes to acoustics and sound absorption. Textiles are porous materials such as nonwoven, woven and knitted fabrics. In a study of how down fibre assembly behave when it comes to sound absorption the authors conclude that in general the fractal dimensions for down fibre assembly, increases with fibre mass and decreases with the porosity (Yang, S. et al 2011) and this could be likened with textiles but depends on what frequency that is of interest.

A textile is not a homogenous material; it doesn’t have the same properties in every angle. According to standard ISO 11654:1997, the material should be homogenous in order to convert it from measurements from an impedance tube and apply it to the measuring methods of a reverberation room (ISO 11654:1997). Although textiles also have promising noise absorption properties, especially nonwoven, the challenge though, lies in producing it in an aesthetically pleasing appearance. The nonwoven are usually draped with a woven fabric. Plain weft knitted fabric has also been up for proposal when it comes to sound absorption, but the sound absorption performance isn’t that good (Yanping, L. & Hong, H. 2010).

According to the author of *"Sound Absorption Behavior of Knitted Spacer Fabrics"* there are studies that focus on improving the noise absorption ability of knitted fabrics with producing spacer fabrics. The study showed that a spacer fabric composed of two weft-knitted surface layers with a uniform pattern of micro pores, with a spacer yarn of monofilaments could provide reasonable absorbability at mid-high frequencies. This could provide an appearance and structure that are designable and this characteristic can raise their value, even though the knitted fabrics are more expensive (Yanping, L. & Hong, H. 2010).

In a study of an auditorium, used both for music and lectures, wall panels were used to increase the perception of sound. The dimensions were 60-50 mm plus a 10 mm cavity from the wall. The wall panels were covered with “open-cell” textiles and showed considerable improvement compared to earlier tests with an acoustic plaster.
They also tested a flexible solution of hanging curtains on the wall with a distance. The larger the distance, the higher the absorption of low frequencies was, which could be hard to attain with only textiles. What also mattered was if the curtains were hanged flat or folded where the folded showing a more effective sound absorption (Heylighen, A., et al. 2010). This shows that textiles are in a rising and developing position when it comes to sound absorption.

In the world today there are both natural fibres and manufactured fibres. To get a hint of how the distribution of fibres over the world looks like, the fibre demand for 2005 in the world is shown in table IV and also to see how much the fibre production has grown in the last years the distribution of 2011 is shown in table V.

Table IV: World fibre demand 2005 (million tons) Reference: (Fletcher, K. 2008)

Natural Fibres	**Million tons**
Raw cotton	24.40
Raw wool	1.23
Raw silk	0.13
Total	25.76

Manufactured Fibres	**Million tons**
Acrylic	2.63
Nylon	3.92
Polyester	24.70
Total	31.25

Table V: World fibre production 2011 (million tons). Reference: Aizenshtein, E. M. (2012)

Fibre production 2011	**Million tons**
Natural fibres	33.1
Manufactured fibres	51
- Polyester	-Approaching 39

3.1 Cotton

Cotton is one of the most used fibres when it comes to interior design and fashion, and is therefore of interest for this project (Snidare, U. 1994).

In order to classify cotton it's based on its grade and staple length. The grade of cotton is determined by three factors; colour, leaf content and preparation during ginning. The staple length is determined by comparing the length of the fibre with the standard calibration cotton fibre (Yogeshwar, K. et al. 1999). There are many different types of cotton, but the one used for spinning into yarns is called mature cotton or lint (Humphries, M. 2009). The best cottons are grown in Sea Island, Pima and Egypt. These fibres are not only the longest but also the softest and finest fibres (Humphries, M 2009). Cotton still accounts for more than a third of all fibres used excluding jute. The distribution of cotton production in 2005 was for China 24%, USA 21%, India 17% and Pakistan 9% (Humphries, M. 2009).

The properties of cotton is absorbent, comfortable, cool hand and with excellent static resistance. It has good strength when dry but also gets 25 percent stronger when wet. Cotton is not easy care without treatment, it's easily wrinkled, shrinks when washed and can also mildew. Cotton and polyester together accounts for over 80% of the global usage of textiles (Fletcher, K. 2008).

3.4 Nonwoven

Textile material have been commonly used for sound absorption and particularly nonwoven fabrics because of their special structure (Kosuge et al., 2005). The usage of nonwovens has grown rapidly in the 21st century (Humphries, M. 2009). Nonwovens have a varied usage for medical, construction, geotextile, transportation, agriculture, packaging and filtration and of course apparel and furnishings.

A nonwoven fabric is a fabric made directly from fibres and there are many methods to achieving these fabrics including mechanical, thermal and chemical bonding. This has also given the rise to composites where two or more materials are combined in one fabric (Humphries, M. 2009).

The most common way to make nonwovens are by needled punched or by spun bonding. The needled punched means that the fibres are joined together with several needle sticks per cm^2 and as the fibres lay random crosswise or lengthwise and by that tangling some of the fibres as the needles goes in and out, gives a product that are flexible with good strength properties (Byggros.com). Spun bonding on the other hand means holding filaments together just after they are extruded from a spinneret. Nonwovens can also be spunbonded by melding, which is when the filaments are held together by heating. Thermally bonded nonwovens are manufactured by endless fibres that are melted together. This type of nonwoven gets stiffer than the needled ones due to the manufacturing process (Byggros.com). The "skin" of the filament have a lower softening point compared to the core of the filament and when heat is applied, they melt together (Humphries, M. 2009). Nonwoven materials can either be needled or thermally bonded and also be a combination of needling and be thermally bonded afterwards.

3.3 Mineral wool

Mineral wool is a is a generic name for building material made by mineral fibres which is used for insulation in first hand but also used for sound absorption. The fibres are long and thin and form a porous mass.

Mineral wool can be divided in two main types, glass wool and rock wool, depending on base material. Mineral wool not only insulates from heat but also absorbs sound. This material is usually used for insulation but also in inner walls where heat insulation is not needed.

Glass wool is usually made from raw material of recycled glass or sand, SiO_2. The raw material melts at 1400 °C and the melted mass is lead to rotating spinners where the glass are hurled through small holes and then solidifies. The thin threads of glass are processed together with phenolic resin and 0,5% mineral oil to bind dust. Then the glass wool is formed into insulation boards or other products. The material is non-combustible (SP 2013). Glass wool could also have some health aspects since it can cause dust when insulating a building. Glassfibrewool can cause skin irritations for sensitive persons when contact with the skin (Euceb 2013).

Rock wool consists of diabase which is melted together with coke at 1600 °C, the fibres are dragged out of rotating wheals from the melted mass. Rock wool, as with the glass wool, can be formed into insulation boards when adding phenolic resin. The material has good insulation properties and is also sound absorbing and is used for insulating floors and ceilings. Rock wool is also used as fire protection when building buildnings (Burström, P.G., 2007).

3.2 Polyester

A lot of nonwoven materials are also derived from polyester, as for other applications. The Global production of all fibres were in 2011 84.1 million tons, including both chemical fibres and natural fibres. The chemical fibres stood for 51 million tons and the dominant fibre was polyester with a total volume approaching 39 million tons. That constitutes roughly 80% of the global output of chemical fibres. 60% of the global fibre market is unchallenged placed in China (Aizenshtein, E. M. 2012). Polyester is a polymer, which is material that is cheap, simple and easy to manufacture. Polymers are also energy efficient and the applications are almost endless. 75% of all professional chemists work with polymers in one way or the other (Albertsson, A.C. et al. 2011).

The original version of polyester is a polymer called PET for polyethyleneterephtalat. Polyester is melt spun and drawn after the fibre is made (Humphries, M. 2009). Polyester is a diverse and large family and can vary a lot. They have diverse ways to use it with widely different properties (Albertsson, A.C. et al. 2011). The properties of polyester are among others good strength and abrasion resistance, good resilience and high modulus, which mean that it is elastic and can recover well from strain. It conducts moisture away and dries fast. The wrinkle resistance is good and it is fairly rigid. It is also used as fibrefill, stuffing for pillows, insulation, batting etc (Humphries, M. 2009).

Nonwovens is rapidly progressing products and PES will be the main source of raw material for this type of products regardless of the method of manufacture according to the author of *"World production and consumption of polyester fibres and yarn. Status and prospects for the Russian market"(*Aizenshtein, E.M. 2007). In the Nonwoven industry today polypropylene and polyester makes up to over 50% by weight of the consumption of material used, and the waste from this increases every year (Ching-Wen, L. et al 2005).

Within the textile industry, the nonwovens are one of the fastest growing segments and make up to roughly one third of the fibre industry. Only the polyester sector of nonwovens in the world by year 2000, was up to 22,5% and the polypropylene is 63% (Ching-Wen, L. et al 2005).

The production of polyester in the world in 2002 attained a record level of 20.4 million tons including both fibres and complex filaments (Aizenshtein, EM 2003). Senior members of “Great American Group” confirm that their research forecast that the nonwoven sector will reach 20% of global textile industry by the year of 2017 (Man-Made Textiles In India, 2012).

However there is also an increasing waste generated from the nonwoven industry, which cause many pollution problems. Therefore recycling and reusing fibrous waste is a very important task to take under consideration in order to reduce environmental loading and to promote the most effective use of resources (Ching-Wen, L. et al 2005).

There are studies showing that textiles are highly competitive as a sound absorption material with the known sound proofing materials. The efficiency of sound absorption relate to the structure and thickness of the materials regardless of whether it’s virgin or recycled. The results from this showed that using recycled nonwoven selvages to produce new composites for sound absorption can reduce the textile waste problem (Ching-Wen, L. et al 2005) also shown in "*World production and consumption of polyester fibres and yarn. Status and prospects for the Russian market"*, that the cost of producing nonwovens can be reduced significantly, on average by 30%, by using fibres made from secondary PET (Aizenshtein, E.M. 2007). According to a study *“Recycling polyester and Polypropylene Nonwoven selvages to produce sound absorption composites*”, it is possible to recycle the selvages of both polyester and polypropylene to make a functional composite for sound absorption. Sawdust was also added to the composites made in this study. The results showed that the absorption coefficients increased with the thickness of the composites but decreased with the density (Ching-Wen, L. et al 2005). A composite is a material which is made from several different substances, and where the different materials contribute with their own characteristics (*Nationalenceklopedin* 2013).

On the nonwoven market today there are discussions about whether the sound absorbing materials have to be a bulky mineral wool or if it is possible to attain good sound absorbing properties even without bulky material.
According to *"Acoustic textiles-lighter, thinner and more sound-absorbent"*, there is a study where the writer wants to show that size isn’t everything in the world of acoustics. The writer claims that by understanding the factors that control sound absorption, it is possible to design a thin lightweight textile that can replace a bulky material that usually are used as sound absorber (Coates, M. & Kierzkowsld, M. 2002).

Effective sound absorption of a porous absorber is achieved when the thickness of the material is about one tenth of the wavelength of the incipient sound. A thin porous sheet or textile can be an alternative sound absorber. If it’s mounted at some distance in front of a rigid backing or a wall for example, sound absorption is achieved. The thin textile has a high flow resistance in a very thin layer in contrast to a bulky fibrous material. If the flow resistance is right the thin textile can absorb almost as much sound as a bulky one. Therefore the textile could be an effective substitute for the bulky fibrous absorber (Coates, M. & Kierzkowsld, M. 2002).

4 Method

4.1 Introduction

The method used in this thesis is an inductive approach based on literature search, study visits, tests according to standards and situational analysis search on internet. The literature is based on both books and scientific articles, licentiate thesis and PhD thesis. Some of the sources are used more than others since they are considered being very up to date, written recently by an acoustician who is active within the acoustic branch and also have knowledge of textiles. The peer reviewed articles are also used in wide extent since most of them are written recently and are therefore considered being updated about the subject and everything that happens in the industry.

The database Summon which can be reached from the website of the University of Borås/Library. Many different words for searching have been used, as sound absorption, acoustics, frequency, audibility, sound wave, sound pressure level among others.

The aim for this experiment is to see which of textiles are the most suitable for this type of product and also if it is possible to reach a sound classification C with only textiles or if batting have to be used. The goal is to, based on the result given, choose material with enough sound absorption properties and also with environment and cost in mind to proceed with in order to make a sound absorbing wall panel. A specification of requirements for the product in mind will be stated and also a shorter explanation of how the experiment have been performed. In the following chapter number *5 Experiment – The implementation*, will follow a calculation of reverberation time for a standard bedroom of $3 \cdot 4 \cdot 2.5$ m, with and without wall panels and also a calculation of how many wall panels will be needed to reach the demands for dB limits according to BBR

4.2 Specification of requirement

The specifications for this wall panel have been set with regards to the products available on the market today and taking under consideration the aesthetic appearance. Into account has also been taking the fact that with a smaller depth, a lower sound classification will be attained. Also has product development procedures been taking under consideration such as price and environmental aspect, the specification is shown in Table VI.

Table VI. Specification of requirements

Demands	Description
Dimensions	Depth: maximun 5 cm At this stage in the process it's not relevant what length or width the product has but the depth
Sound calssifications	According to standard of sound classfication a class C should be attained as a minimun
Material; 1st layer	Should be a bit sound absorbing, but light enough to not reflect the higher frequencies

	Easy to print on, or the fabric should have a design that's beautiful and interesting in the eyes of the customer Not too expensive to manufacture, but a price is not specified.
Material; Frame	Not specified
Material; Filling	Mineral wool / Polyester nonwoven

4.3 Methods used for measuring sound absorption

This chapter refers to explain in short terms how the measurements were done and what test specimens of textiles were used.

4.3.1 Kunds Tube

In order to measure small samples of materials, as textiles, the test method will give an initial approximate indication of the sound absorbing qualities of the material. The method is according to the international standard ISO 354. That is a full-scale measurement where diffuse sound field is used. Since it was not possible to do full-scale measurements, only the values from Kundt's tube, with only perpendicular incident, was used to compare the values to a sound classification according to ISO 11654. Because of the limited reliability of these results when not covering the whole frequency range according to standard, awareness is taken to the fact that the sound absorption most likely will be higher even for the lower frequencies with diffuse sound field than with the perpendicular incident.

The procedure with Kundt's tube, is to be done in a rigid tube, where the sample to be tested is attached at the end of the tube and from the other end the sound is internally guided and forced to propagate along the tube axis. The tube has a circular cross section and the fabric sample is cut out to fit precisely at the end of the tube. Close to the fabric two microphones are attached, one which measures the sound waves before the reflection and one that measures the sound waves reflected from the sample. Such tube, used to determine the acoustic properties of a sample, is called an impedance tube, or Kundt's tube. As long as the tube diameter is small compared to the wavelength, it produces a plane sound wave (Möser, M. 2009). In figure VI a schematic picture of an impedance tube are shown and in Figure VII are following pictures from the measurements.

Figure VI. A schematic picture of Kundt's tube (Wintzell 2013).

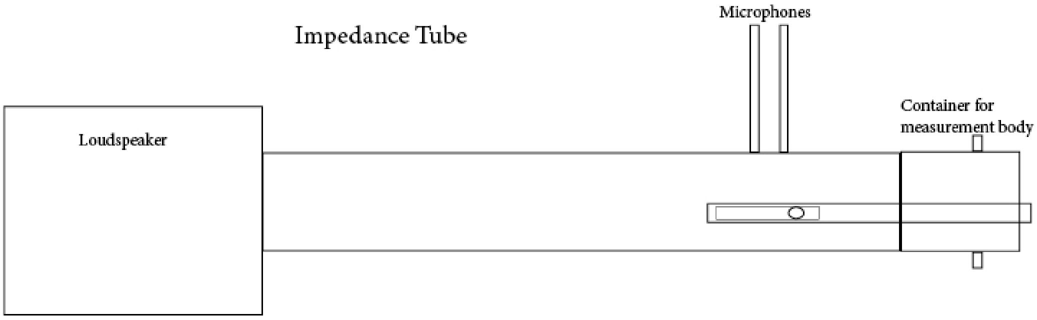
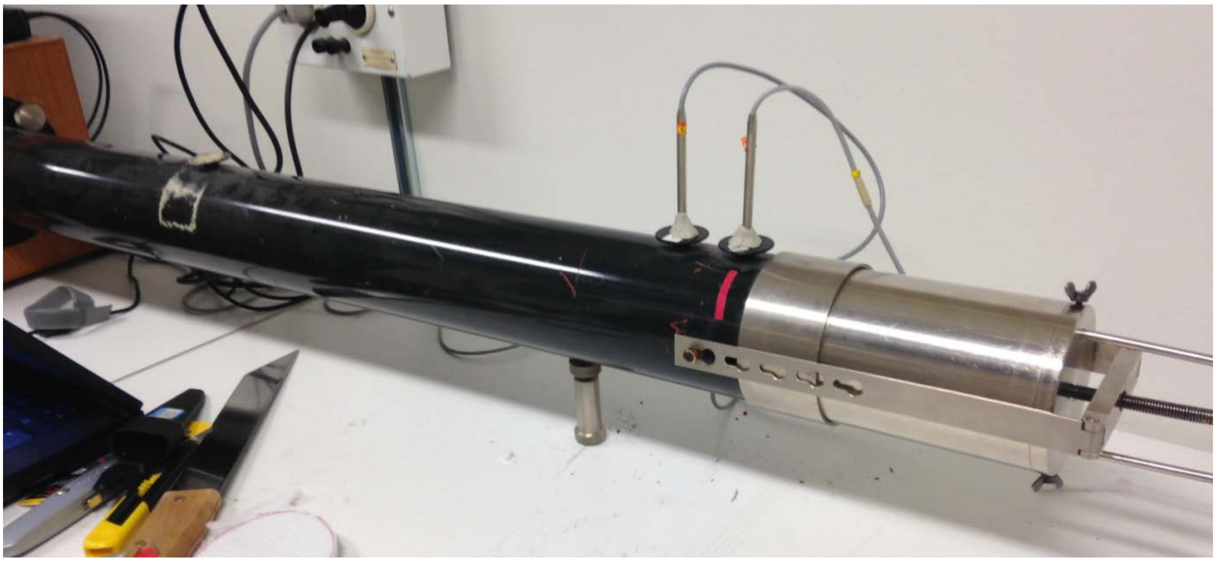
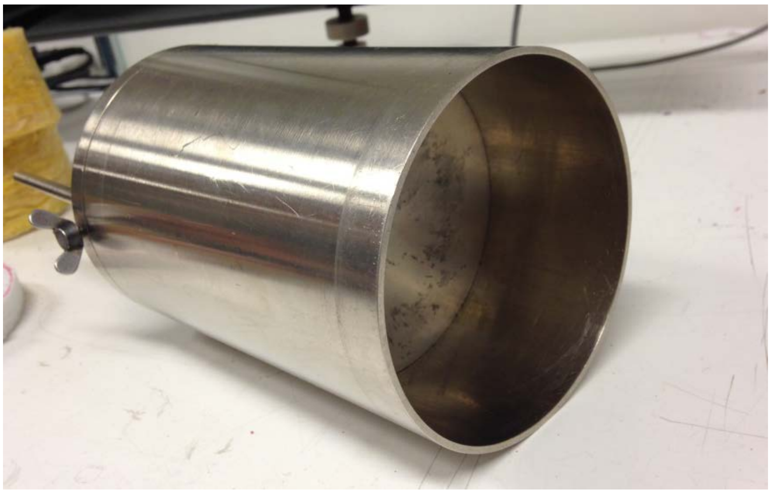


Figure VII. Pictures from measurement in Kundt's tube (Wintzell 2013)



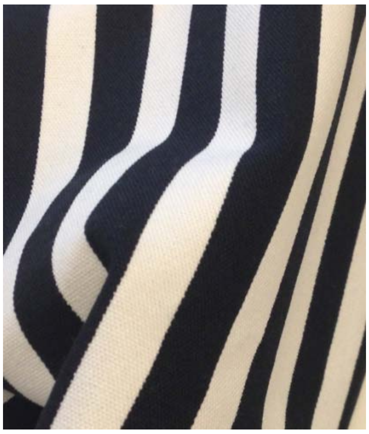


4.3.2 Analysis of textiles

In order to make a systematic structure, the following materials were chosen from the range of IKEA. The polyester fleece was chosen mostly because its aesthetic appeal and interesting structure, and also two different cotton weaves were chosen since cotton is one of the most common materials used in interior.

Table VII. The different textiles used for the measurements

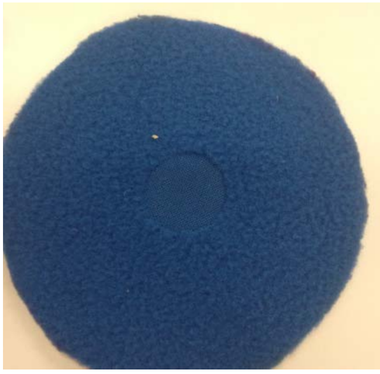
Name	Material	Others
IKEA PS 	100% polyester	fleece avaliable in blue and red colour

ANNBETH 	100% cotton	printed on plain weave black and white
SOFIA 	100% cotton	plain weave, yarn dyed multi colours

5 Experiment – The implementation

To start with, a circular piece of every test specimen of the diameter 10cm were cut out. Then they were seperately put into the container for measurement, which was fasten to the impedance tube, with a hinged arm of steel. The depth of the container could be adjusted, according to the specification of requirements the depth was set to 50mm so that’s the depth used for every test.

Figure VIII. Textile material

Blue	Black&White	Multi
		

Also five different battings were used as different polyester nonwovens with different thickness and weight and also a classic mineral wool.

Figure IX. Batting material

Batting nr 1	Batting nr 2	Batting nr 3	Batting nr 4	Batting nr 5
				

After adjusting the depth and fastening the container at the tube, white noise was sent towards the test specimen for 62 seconds. On top of the tube two microphones were attached, one that measures the initial sound and one which measures the sound bouncing back from the test specimen. From the information attained from this, several values could be distinguished. These values were converted into a program called MATLAB, which made it into values usable in Excel, which in turn made the values analysable to use according to standard. After the measurements a recalculation according to standard ISO354 was made from one-third octave bands into octave bands and then compared to the reference cure according to standard ISO654 to get the sound classification. The results are shown in the appendix 8.2, and the most relevant results are shown in next chapter named *6 Results*.

5.1 Calculations with dampening

From the measurements in Kundt's tube, a decision were reached to use the combination "Blue+4", which is a polyester nonwoven batting with the polyester knitted fabric "IKEA PS". For further information about this combination and how the decision was made, the results are shown in chapter *6 Results.*

Following calculations are on different scenarios, in reverberation time with and without sound absorbing wall panels. For the wall panels calculations will be done considering the value attained from the measurements in Kundt's tube and the combination "Blue+4". There are several formulas for determining reverberation time and therefore a lot of discussions about which one to use (Passero, C.R.M. & Zannin, P.H.T. 2010). For this project Sabine's formula is the one to be used.

When doing rough calculations for the reverberation in a room, standardized absorption area of 10 m^2S are used. This absorption area refers to a normal dampened room of 34.9m^3 (ISO 025268) To a normal dampened room, belongs a bookshelf, bed, chair and a carpet for instance. A normal size for a bedroom could be estimated to 4·3 m and the height to 2.5 m, which gives the room a total volume of 30 m^3, which is in order of magnitude as with the standardized room.
It is important to notice that for these calculations with Sabine's formula, some simplifications have to be considered. The absorption area assumes to be evenly spread in the room so with only one wall panel it might be difficult to distribute the absorption. Some other phenomenon can occur as flutter echo, which is when the sound only bounces between two walls (ISO 025268).

5.2 Calculation of reverberation time

The essential absorption of 0,1 m^2S/m^2 floor area (Åkerlöf, L. 2001) which is considered the facts to calculate with for an empty room, gives for this room an essential absorption area of 1,2 m^2S.

Dimensions of room: $3 \cdot 4$ m = 12 m^2,
Height 2,5 m. Volume: $12 \cdot 2.5 = 30$ m^3
Essential absorption: $12 \cdot 0.1 = 1.2$ m^2S

If we choose values from one of the measurements with "Blue+4", which is the one chosen for procedure, where the value for 2000 Hz is estimated from reviewing the test results we get the values shown in table VIII. This gives according to standard a weighted absorption coefficient $\alpha_w = 0.7$.

Table VIII. Values for "Blue+4".

Frequency (Hz)	Absorption coefficient (alpha)
250	0.42
500	0.72
1000	0.96
2000	0.94

5.2.1 Reverberation time for empty room with wall panel

These calculations correspond to an empty room with the essential dampening according to earlier written, but with wall panels. The size of the absorbing wall panel is estimated to 1.2 · 1m, which gives a total area of $1.2 m^2$.
We use the values from "Blue+4" which was the test specimen chosen for procedure from the tests, with the weighted absorption coefficient ($\alpha_{w)}$ 0.7.
To get the absorption factor (m^2S) for the wall panel, which is the weighted absorption coefficient (α_w) · the area of the absorbing wall panel (m^2)(ISO 025268):

$$0.7 \cdot 1.2 = 0.84\ m^2S.$$

Dimensions of room:	$30\ m^3$
Essential absorption:	$1.2\ m^2S$
Area of wall panel:	$1.2\ m^2$
α_w:	0.7
Absorption area of wall panel:	$0.84\ m^2S$

To calculate the total sum of absorption area (m^2S), the total absorption area of one wall panel, which is what will be put in the room, and adding it to the essential absorption area of the room: $0.84 + 1.2 = 2.04\ m^2S$

$$\text{Reverberation time}(T_R) = 0.16\ \frac{V}{A}$$

V = volume of room	In this case: $30\ m^3$
A = sum of absorption	In this case: $2.04\ m^2S$

Reverberation time(s):

$$0.16\ \frac{30}{2.04} = 2.35294 \approx 2.4\ s$$

This reverberation time is by far too long for a bedroom, so if the bedroom is unfurnished and only the wall panels were put in, this would mean that in order to get an reverberation time of 0.5 s as a maximum, according to the demands from BBR, we would need an total sum of absorption area of 8 m^{2}S according to following calculations. As according to the same calculations this would also mean that 10 pieces of wall panel of the dimension 1.2m^2 would be needed.

T_R = 0.5
Wall panel + essential absorption= 1.2 + 0.84 m^{2}S = 2.04 m^{2}S

$$T_R = 0.16\ \frac{V}{A}$$

$$0.5 = 0.16\ \frac{30}{A}$$

$$A = 9.6\ \text{m}^2\text{S}$$

To get how much absorption area the wall panels must have, the essential absorption of the room is subtracted from the total absorption:

$$9.6 - 1.2 = 8.4\ \text{m}^2\text{S}$$

Then to calculate how many wall panels this would mean, the absorption area of the room is divided by the absorption area of one wall panel, which gives:

$$\frac{8.4}{0.84} = 10 \text{ pieces of wall panels}$$

5.2.2 For a normal dampened room

These calculations correspond to a normal dampened room, normally furnished, with a total absorption area 10 m^2S. Fist a figure of a normal dampened room are shown in Figure X.

Figure X. Normal dampened room (Wintzell 2013)

Dimensions of room: 30m^3
Essential absorption: 10m^2S

$$T_R = 0.16 \frac{V}{A}$$

V = volume of room 30 m^3
A = sum of absorption 10 m^2S

Reverberation time (s):

0.16 · 30 / 10 = 0.48 s

This result lies more within the demands for a regular bedroom, even though if a really quiet bedroom is desirable this might not be enough.

5.2.3 For a normal dampened room with one wall panel

These calculations correspond to a normal dampened room, normally furnished, with a total absorption area 10 m^2S. Added to this is one wall panel as shown in figure XI.

Figure XI. Normal dampened room with one wall panel of the dimensions 120·100·5 mm with the material "Blue+4" (Wintzell 2013).

Dimensions of room: 30 m^3
Essential absorption: 10 m^2S
Absorption area wall panel: 0.84 m^2S

Total sum of absorption area (m^2S):

0.84 + 10 = 10.84 m^2S

$$T_R = 0.16\ \frac{V}{A}$$

V = volume of room 30 m^3
A = sum of absorption 10.84 m^2S

Reverberation time (s):

0.16 · 30 / 10.84 = 0.4428 ≈ 0.44 s

The calculations in reverberation time shows that only one wall panel in a normal dampened bedroom doesn't give that big of effect. The difference is only 0.04 s, which is not really a noticeable difference for a regular person, even though it's still a difference in the context of reverberation time. The calculations also shows that for this small room, with a normal dampening of 10 m^2S already have a short reverberation time and is not really needed for further dampening unless as in this case it is for a bedroom. In a bedroom most of the absorption area is located to the bed, which means it is not spread evenly on all areas, as the formula assumes. This means that it could probably be of use to put in a few sound absorbing wall panels to actually dampen the sound in the room. This will most likely enhance the perception of the sound conditions in the room.

If the goal for reverberation time is set to 0.3 s:

Dimensions of room: 30 m^3
Essential absorption: 10 m^2S
Absorption wall panel: ?
Reverberation time: 0.3 s

$$0.3 = 0.16\ \frac{30}{A}$$

$$A = 16\ m^2S$$

$$16 – 10 = 6\ m^2S$$

$$\frac{6}{0.84} = 7.14 \text{ pieces of wall panels}$$

Which gives a total area of wall panels:
$7.14 \cdot 1.2 = 8.56\ m^2$

This shows that a total absorption area of the wall panels would have to be 6 m^2S, or about 7 pieces of the wall panel to reach the goal.

5.3 Calculations of sound pressure level

In order to calculate how many absorbers of the dimensions 1 · 1,2 m, with the material of "Blue+4", will be needed to reach the demands of 30 dB in a bedroom, the formula which were described earlier in chapter *2.3.4 Direct sound filed and reverberation sound filed,* $L_p = L_w + 10log\left(\frac{4}{A}\right)$, sound pressure = sound effect is used.

Here will follow three different scenarios with a normal dampened room. It starts with a sound pressure level at 40 dB, which means that it should be lowered by 10 dB. For scenario nr 2 it starts at 36 dB, means lowering by 6 dB. As the final scenario it starts with a sound pressure level of 33 dB, which means that it only have to be lowered by 3 dB. 3 dB actually makes a audible difference to a regular person. Even 1 dB makes a difference but not as much for dampening sound, but more when it comes to the experience and perception of sound as for music, speech and other euphony.

The aim is to reach the demands of a sound pressure level of 30 dB in a bedroom of the dimensions 3·4 m = 12 m^2, height 2.5 m
Total wall area of the room:

$$2.5 \cdot 3 + 2.5 \cdot 4 = 17.5\ m^2$$
$$17.5 \cdot 2 = 35\ m^2$$
Total wall area of the room: 35 m^2

5.3.1 Scenario nr 1

The sound pressure level is 40 dB and should be reduced to 30 dB, as the demands of BBR. To start with, a calculation of sound effect, L_w, will be done and the room is assumed to be furnished with normal dampening.

$$L_p = L_w + 10log\left(\frac{4}{A}\right)$$

L_p = Sound pressure level
L_w = Sound effect
A = area of sound absorption

Since we know the sound pressure level at origin and also have a normal dampened room, the sound effect can be calculated.

L_p = 40dB
A = 10m^{2}S
L_w = ?

$$40 = L_w + 10log\left(\frac{4}{A}\right)$$

$$L_w = 40 - 10log\left(\frac{4}{10}\right)$$

$$L_w = 43.979 \approx 44 \text{ dB}$$

The question now is how much sound absorbing area(m^{2}S) is needed to lower the sound pressure level by 10 dB. The same formula can be used:

$$L_p = L_w + 10log\left(\frac{4}{A}\right)$$

L_p = 30 dB
L_w = 44 dB
A = ?

$$30 = 44 + 10log\left(\frac{4}{A}\right)$$

$$10log\left(\frac{4}{A}\right) = 30 - 44 = -14$$

$$log\left(\frac{4}{A}\right) = -\frac{14}{10} = -1.4$$

$$\frac{4}{A} = 10^{-1.4}$$

$$A = \frac{4}{10^{-1.4}} = 100.48 \text{ m}^2\text{S}$$

The total absorbing area must be about 100 m^2S to dampen the room with 10 dB. This would mean 100 – 10 m^2S = 90 m^2S absorption area addition to the normal dampening in the room. For a wall panel of the dimensions 1.2·1 m = 1.2 m^2 of the material "Blue+4", only have a absorption area of 0.84 m^2S. This means 107 pieces of the wall panel. This in turn, would be impossible to achieve since the total wall area of the room only is 35 m^2.

5.3.2 Scenario nr 2

The sound pressure level is 36 dB and should be reduced to 30 dB, as the demands of BBR.

$$L_p = L_w + 10log\left(\frac{4}{A}\right)$$

L_p = 36 dB
A = 10 m^2S

$$36 = L_w + 10log\left(\frac{4}{10}\right)$$

$$L_w = 36 - 10log\left(\frac{4}{10}\right)$$

$L_w \approx$ 40 dB

$$L_p = L_w + 10log\left(\frac{4}{A}\right)$$

L_p = 30
L_w = 40
A = ?

$$30 = 40 + 10log\left(\frac{4}{A}\right)$$

$$10log\left(\frac{4}{A}\right) = 30 - 40 = -10$$

$$log\left(\frac{4}{A}\right) = \frac{-10}{10} = -1$$

$$\left(\frac{4}{A}\right) = 10^{-1}$$

$$A = \frac{4}{10^{-1}} = 40\ m^2S$$

The total absorbing area must be 40 m^2S to dampen the room with 6 dB. This would mean 40 – 10 m^2S = 30 m^2S absorption area addition to the normal dampening in the room. This means that 30/0,84 = 35,7 pieces of my wall panel. This in turn, wouldn't either be possible to achieve since 35.7·1.2 = 42.86 m^2, and the total wall area of the room only is 35 m^2.

5.3.3 Scenario nr 3

The sound pressure level is 33 dB and should be reduced to 30 dB, as the demands of BBR.

$$L_p = L_w + 10log\left(\frac{4}{A}\right)$$

L_p =33dB
A = 10 m^{2}S
L_w = ?

$$33 = L_w + 10log\left(\frac{4}{10}\right)$$

$$L_w = 33 - 10log\left(\frac{4}{10}\right)$$

$$L_w \approx 36 \text{ dB}$$

$$L_p = L_w + 10log\left(\frac{4}{A}\right)$$

L_p = 30
L_w = 36
A = ?

$$30 = 36 + 10log\left(\frac{4}{A}\right)$$

$$10log\left(\frac{4}{A}\right) = 30 - 36 = -6$$

$$log\left(\frac{4}{A}\right) = \frac{-6}{10} = -0.6$$

$$\frac{4}{A} = 10^{-0,6}$$

$$A = \frac{4}{10^{-0.6}} = 15.92 \text{ m}^2\text{S} \approx 16 \text{ m}^2\text{S}$$

The total absorbing area must be 16 m^{2}S to dampen the room with 3 dB. This would mean 16 - 10 m^{2}S = 6 m^{2}S absorption area addition to the normal dampening in the room.
This means that 6/0.84 = 7.1 pieces of the wall panel. This could actually be possible to achieve since 7 pieces of 7·1.2 = 8.6 m^2, on a total wall area of 35 m^2 means 8.6/35 = 0.2457, 0.2457·100 = 24.57%.
These calculations shows that a reverberation time of 0.3 s for a normally furnished bedroom would need about 7 pieces of the wall panel. That is the same result as the calculations for lowering the sound pressure level from 33 dB to 30 dB.

6 Result of measurements in Kundt's tube

The following tables and diagrams will show the results from measurements in Kundt's tube, which have been done according to standard. In the table xxx all test specimens are specified, a shorter explanation and also to what name they will be referred to in the text are stated. At the end a summary of the test specimen and what sound classification they reached from their results are shown in table IX.

To start with the test results in one-third octave band are shown for each material, and then for some of the best combinations. Then the graphs of each of the best combinations are shown together with the reference curve in octave bands and shorter comments will follow on each graph. The comments will also present what classification each combination have reached. Further the results of combinations that are not directly relevant for this project are shown just because the interesting results for potential further research.

Table IX. Presents respectively each test specimen.

Test Specimen	Material	Nickname
IKEA PS	100% Polyester	"Blue"
ANNBETH	100% cotton	"Black&White"
SOFIA	100% cotton	"Multi"
2xblue+multi	Two layers of the blue polyester fabric IKEA PS and one layer of the 100% cotton fabric SOFIA.	2xblue+multi
2xbule+2xmulti	Two layers of the blue polyester fabric IKEA PS and two layer of the 100% cotton fabric SOFIA.	2xbule+2xmulti
Batting nr 1	A 100% polyester batting, light and fluffy 50mm	"Batt1"
Batting nr 2	A 100% polyester batting Compact nonwoven with a harder surface, 20mm	"Batt2"
Batting nr 3	A 100% polyester batting Compact nonwoven, but not as compact as nr 2, with a harder surface, 50mm	"Batt3"
Batting nr 4	A 100% polyester batting Compact nonwoven, more compact than nr 2, with a much harder surface, 25mm Used in double layers if not specified as "4simple"	"Batt4"
Batting nr 5	Traditional mineral wool, nonwoven, not very compact, 50mm	"Batt5"
Blue + 5	One layer of the polyester fabric referred to as "Blue" in combination with "Batt5"	"Blue+5"

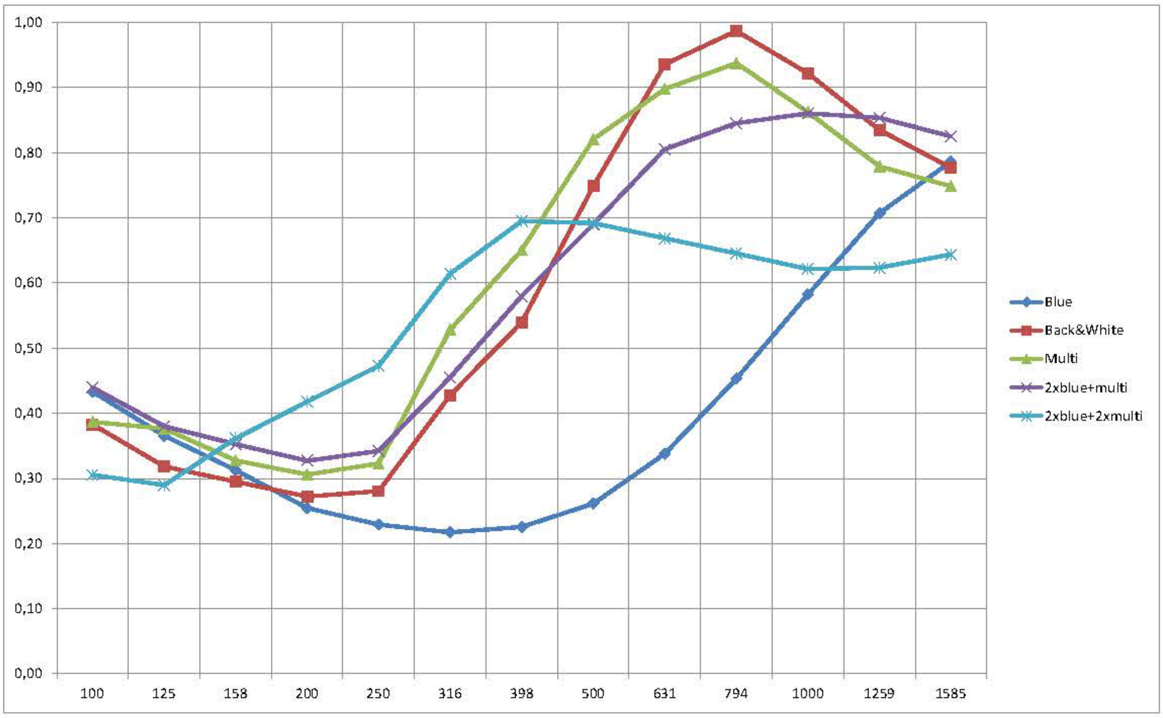
Blue+4	One layer of the polyester fabric referred to as "Blue" in combination with "Batt4" which as earlier stated is two layers of the batting nr 4.	"Blue+4"
Blue+4simple	One layer of the polyester fabric referred to as "Blue" in combination with a simple layer of batting nr 4	"Blue+4simple"
Multi+5	One layer of the multi coloured cotton fabric ANNBETH in combination with the traditional mineral wool	"Multi+5"
Blue+Multi+5	One layer of "Multi", one layer of "Blue" and one layer of Batting nr 5	"Blue+Multi+5"

6.1 Kundts tube measurements

The following tables and diagrams show the results from measurements in Kundt's tube which have been done according to standard. First the result from measuring only textiles are shown, then only the batting materials and then the different combinations. There after some of the chosen materials are shown together with a reference curve. At the end a table with a summary of the tests are shown.

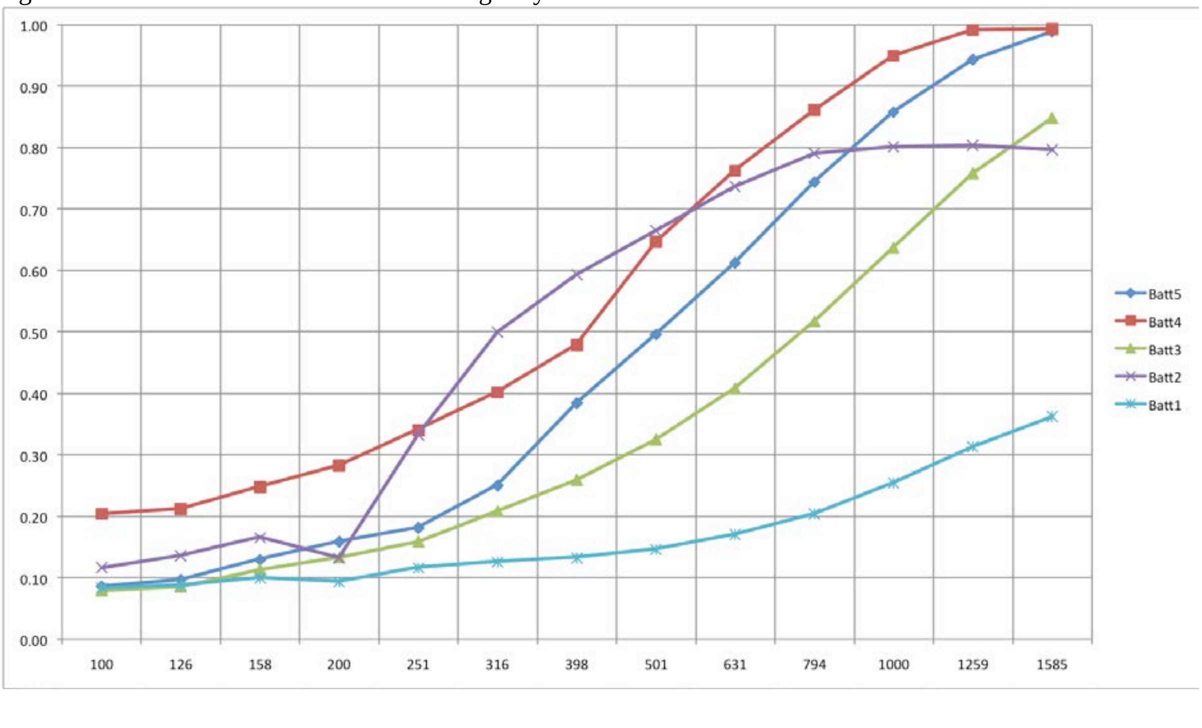
In the diagram the absorption coefficient as a function of frequency are shown, the absorption coefficient highest value is 1 for the y-axis and for the x-axis the maximum frequency value is 1500 Hz.

Figure XII: Test result with textiles only.



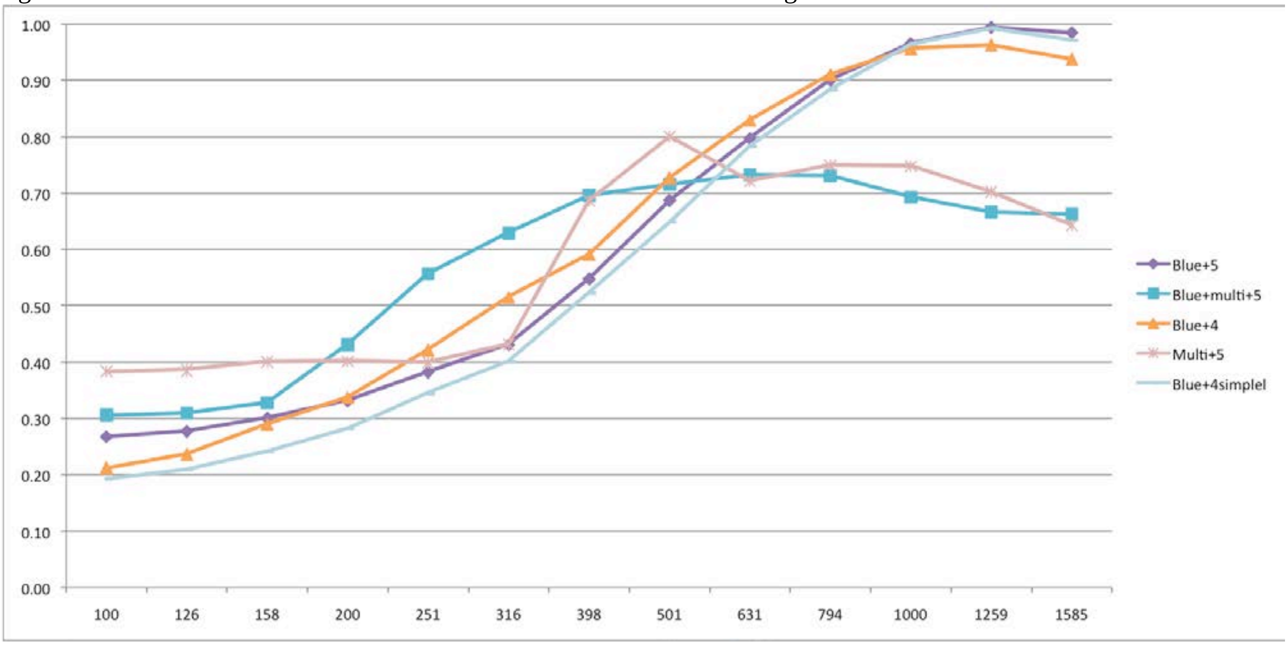
This is interesting because of the surprisingly good results from only using textiles. The one with highest value at 250 Hz is ”2xblue+2xmulti”, which means two layers of the blue polyester fabric and two layers of the multi coloured cotton weave. This combination has relatively high value at 250 Hz, which is the area that could be critical and a challenge to reach a higher value at. The combination was quite early removed from the results to proceed with since it contained too much different textiles and materials to be environmentally friendly.

Figure XIII: Test result from tests with batting only.



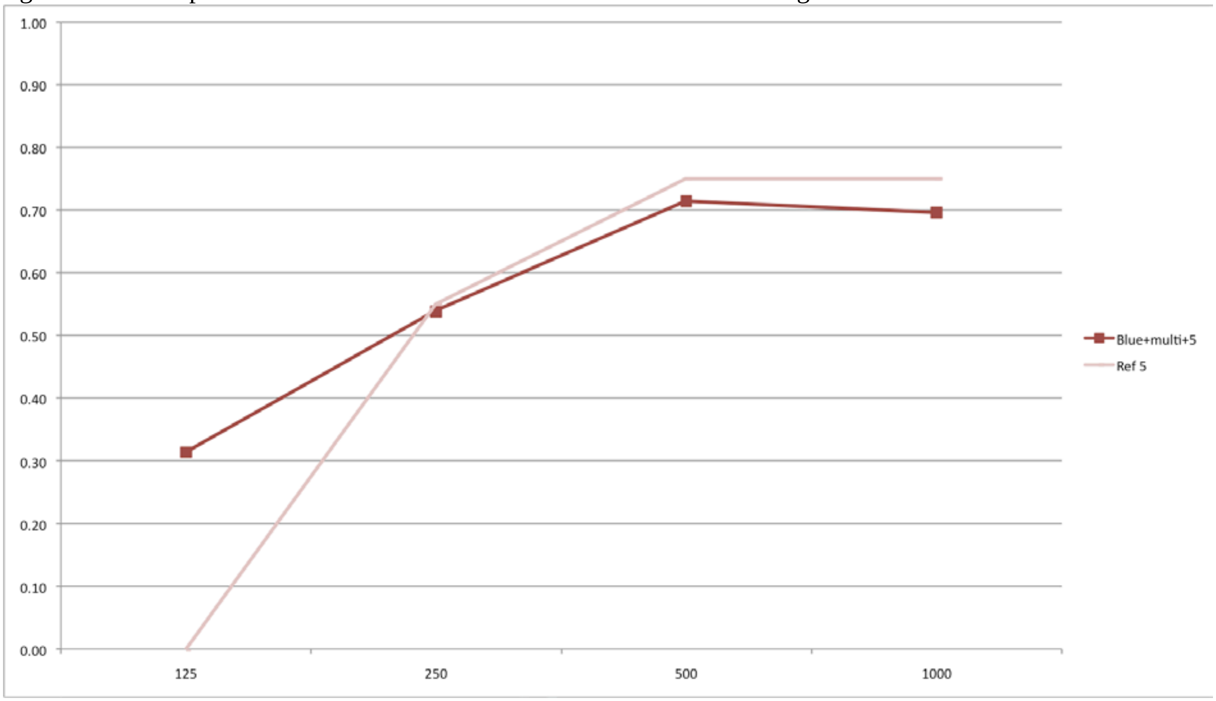
From these results batting number 1, 2 and 3 were excluded instantly due to their low values at 250Hz.

Figure XIV: Test results with different combinations of textiles and batting.



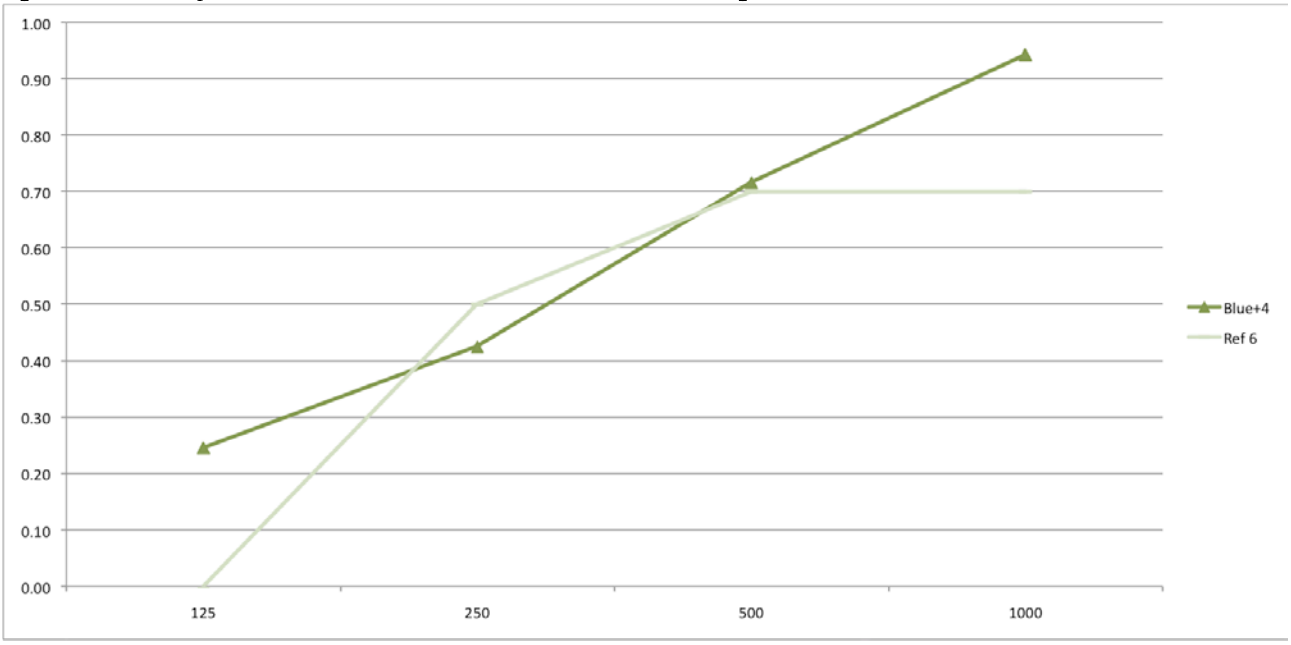
From these results, the best ones were chosen, due to their value at 250 Hz, but also due to the results at higher frequencies, and a recalculation was made from one-third octave band into octave band and then put in relation to a reference curve.

Figure XV: Test specimen combination "Blue+Multi+5" in octavebands together with the reference curve.



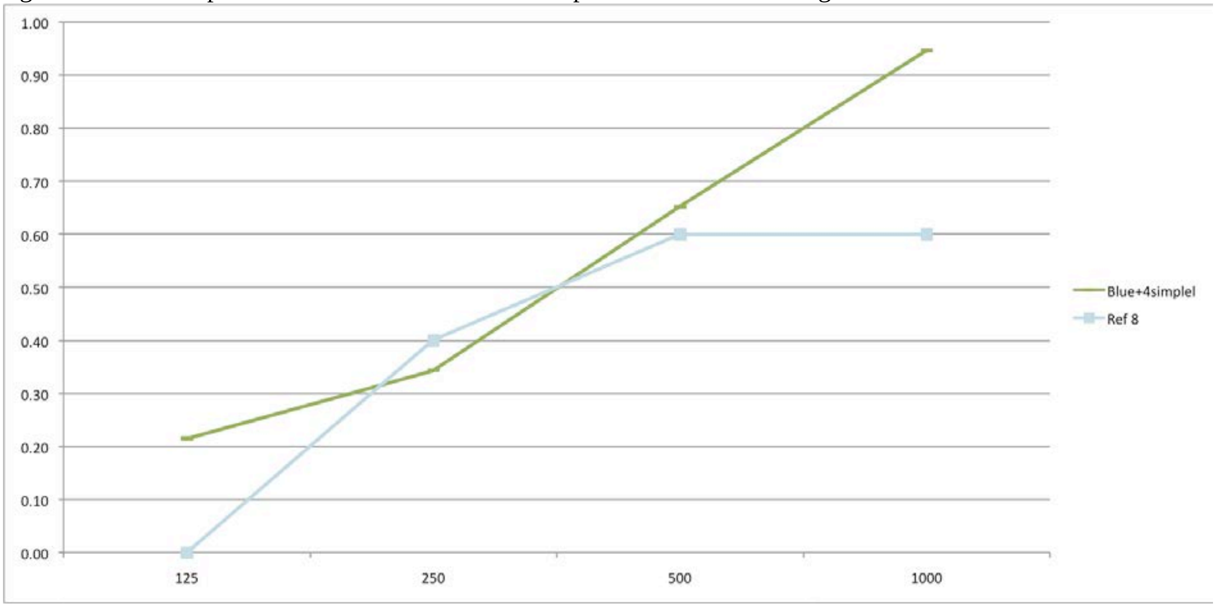
After comparison with the reference curve this combination resulted in a weighted sound absorption coefficient 0.75, which is the highest number within the C – classification.

Figure XVI: Test specimen combination “Blue+4” in octave bands together with the reference curve.



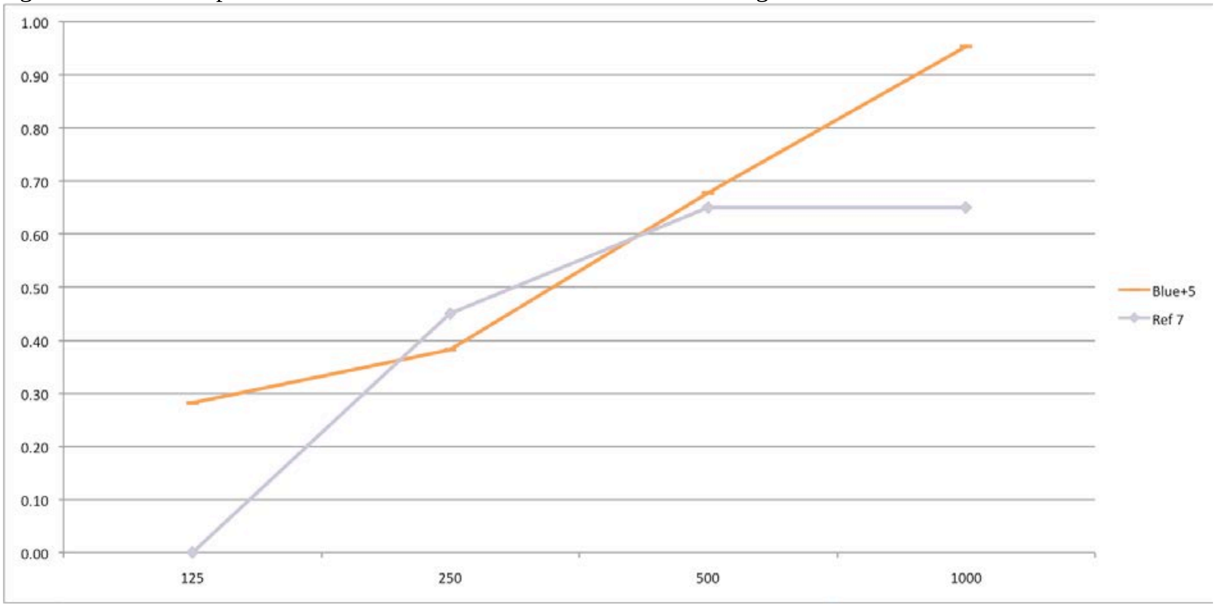
This combination comprises the blue polyester fabric together with double layer of the batting number 4. This also resulted in a classification C, the weighted sound absorption coefficient reached 0,7, which also lies within the higher range of class C.

Figure XVII: Test specimen combination “Blue+4simple” in octave bands together with the reference curve.



To see if it was possible to reach the same result with only one layer of the number 4 battting a test was made. For this combination only a value of 0.6 as the weighted sound absorption coefficient was reached. This means that it is still within the classification C, but not as high as the previous combinations.

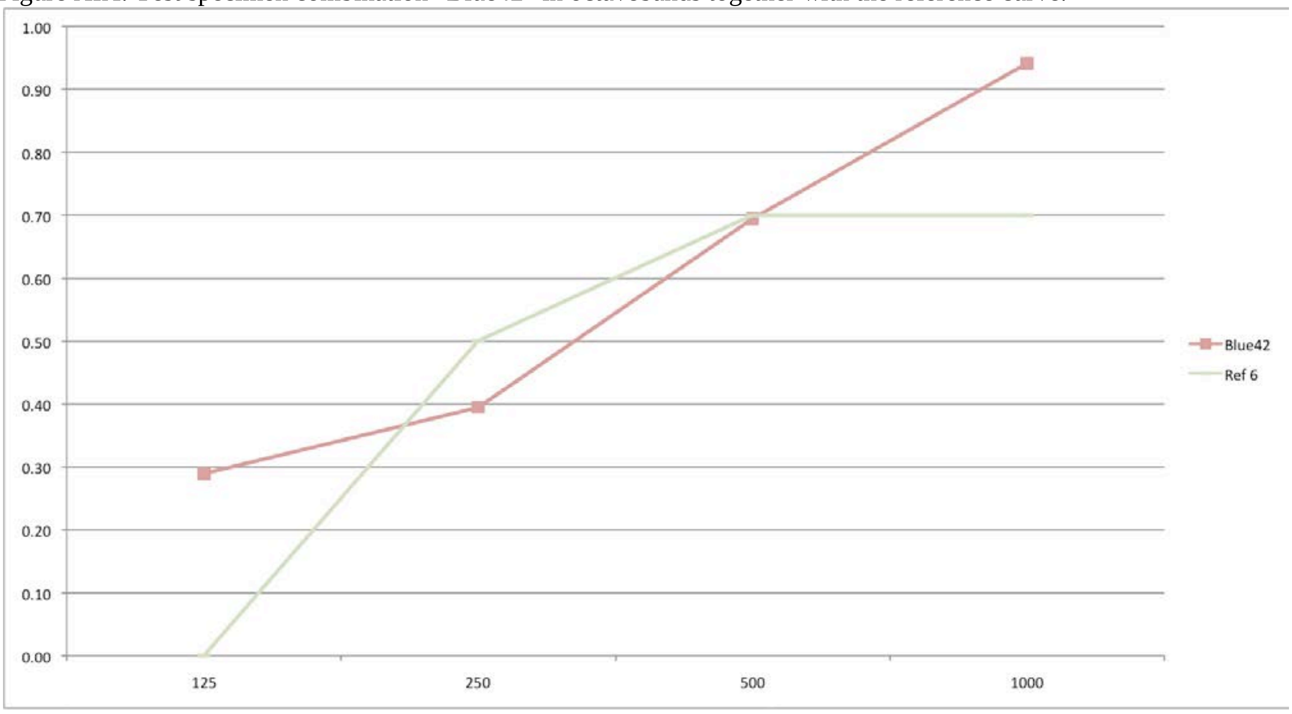
Figure XVIII: Test specimen combination “Blue+5” in octave bands together with the reference curve.



This test comprise “Blue” together with “Batt5” as batting. The result gave a value of 0,65 which is within the classification C range.

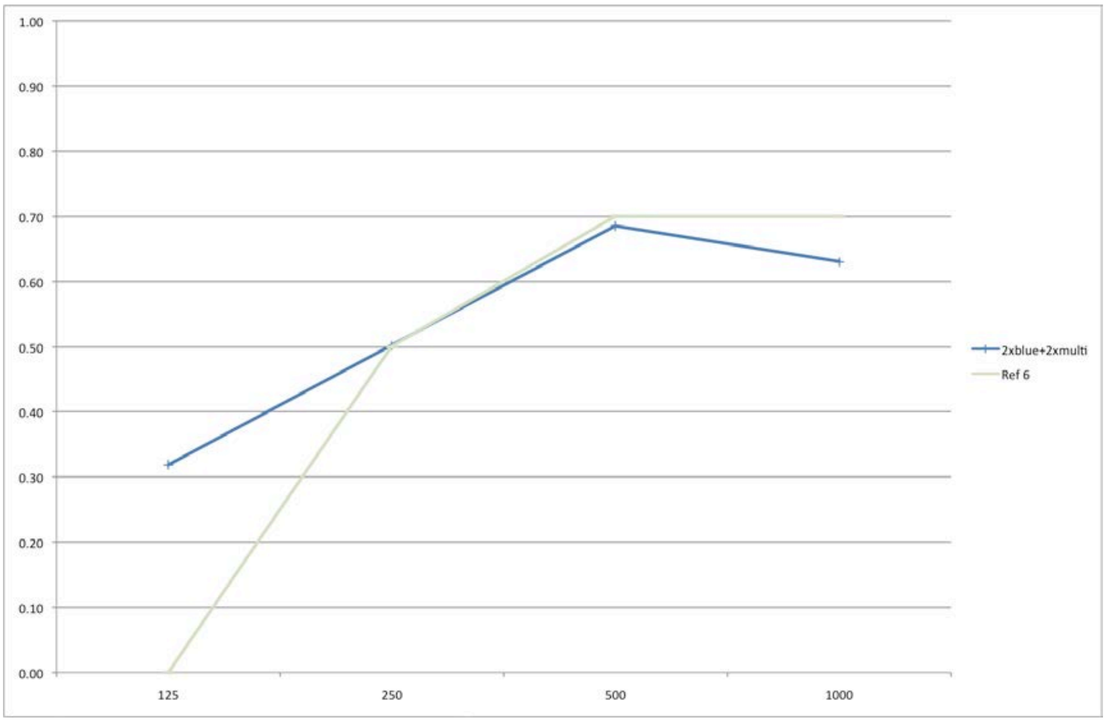
The following two graphs are not directly related to the result of this project but are still interesting as a comparison. The first one shows “Blue42”, which were early excluded from the project due to the fact that “Batt2” didn’t perform good enough in the test. The second one was excluded with respect to environmental aspects and also due to the fact that too many different textile materials and different production methods would end up in a too expensive product.

Figure XIX: Test specimen combination “Blue42” in octavebands together with the reference curve.



Just for interest a test was also made with the blue fabric with one layer of the number 4 batting and added to this was the number 2 batting. This resulted in a coefficient 0.7, just as high as the test object ”Blue+4”, and this combination reached a value of 0.4 at 250 Hz, which also is very close to ”Blue+4”. The reason why this could be of interest is since the batting number 2 is much thinner than batting number 4 and could there fore be of interest since it most likely uses less material. This also leaves an aspect to the fact that the air space behind the material is of interest and significance.

Figure XX: Test specimen combination “2blue+2muli” in octave bands together with the reference curve.



This shows the result from ”2xblue+2xmulti” and in relation to the reference curve it reached a alpha w 0.7, classification C.

Test Specimen	Weighted sound absorption coefficient (α_w)	Sound classification
“Blue”	-	
“Black&White”	-	
“Multi”	-	
“2xblue+multi”	-	
“2xbule+2xmulti”	0.7	C
“Batt1”	-	
“Batt2”	-	
“Batt3”	-	
“Batt4”	-	
“Batt5”	-	
“Blue+5”	0.65	C
“Blue+4”	0.7	C
“Blue+4simple”	0.65	C
“Multi+5”	-	-
“Blue+Multi+5”	0.75	C
“Blue42”	0.7	C

7 Discussion and Conclusion

7.1 Discussion

Interesting results were attained in the test with only using textiles in the combination ”2xblue+2xmulti” because of the surprisingly good results by 250 Hz. The combination was quite early removed from the results to proceed with, since it contained too much different textiles and materials to be environmentally friendly and most likely be too expensive to manufacture due to the different production procedures.

From the results from the test with only batting, number 1, 2 and 3 were excluded instantly due to their results even though a test just for interest was made with the blue fabric “Blue” with one layer of the number 4 batting “Batt4”, and added to this was the number 2 batting “Batt2”. This resulted in a α_w = 0.7, just as high as the test object ”Blue+4”, and this combination reached a value of α_w = 0.4 at 250 Hz, which also is very close to ”Blue+4”. The reason why this could be of interest is since the batting number 2 is much thinner than batting number 4 and could therefore be of interest since it most likely uses less material. This also leaves an aspect to the fact that the air space behind the material is of interest and significance. Even despite this result a decision was made to not proceed with the number two batting due to the fact that batting number 4 still reached higher values and were considered still being within the specification of requirements.
After comparing the best results with the reference curve the combination with the blue polyester fabric together with the multi coloured cotton weave and a classic mineral wool, “Blure+Multi+5” resulted in α_w = 0.75, which is the highest number within the C – classification and also the highest reached in the tests for this project. Due to its many different materials this combination was not chosen to proceed with, with respect to the environmental and cost aspect.
The combination of the blue polyester fabric together with a classic mineral wool, “Batt5”, resulted in a value of 0.65, also classification C. This result was considered too low of value compared to the others, and also it was more interesting to use materials not used traditionally as a sound absorbing material, especially due to the environmental aspect.

The combination which comprise the blue polyester fabric together with double layer of the batting number 4, “Blue+4”, also resulted in a classification C, the weighted sound absorption coefficient reached 0.7, which also lies within the higher range of class C. This is the combination chosen to proceed with since it has only polyester material and still reached a high coefficient. The fact that it only comprises one type of material, gives it an interesting aspect for procedure due to the fact that it increases the possibility to produce a product from recycled materials or to be recycled. A test was also made to see if it was possible to reach the same result with only one layer of the number 4 batting, “Blue+4simple”. This only reached 0.6 as the weighted sound absorption coefficient and this means that it is still within the classification C, but not as high as the previous combinations and therefore was excluded.

After choosing the test object ”Blue+4” a calculation of reverberation time was made for a standard bedroom of the dimensions 3 · 4 · 2.5 m. Starting with calculating the reverberation time for an empty room with just the essential absorption and then with a wall panel comprising the materials ”Blue+4” and with the dimension 1.2 m^2. If we look at the reverberation time, it resulted in 2.4 s. This is by far too long reverberation time for a bedroom. To meet the demands of maximum 0.5 s reverberation time, we would need to put in 10 wall panels of the same dimensions. But of course this is for an unfurnished room and bedrooms are seldom unfurnished but furnished with a bed, wardrobe maybe a carpet and so

on. For this matter a calculation was also made according to a normal dampened room. For a normal dampened room of the same dimensions as before, the reverberation time was calculated to 0.48 s. This time the reverberation time don't need to be lowered since it is even lower that the demands according to BBR. For this project it is still of interest to see if a wall panel would make any difference to the reverberation time.
After calculating with normal dampened room and one wall panel the reverberation time resulted in 0.44 s. The calculations shows that only one wall panel in a normal dampened bedroom doesn't give that big of effect. The difference is only 0.04 s, which is not really a noticeable difference for a regular person, even though it's still a difference in the context of reverberation time. The calculations also shows that for this small room, with a normal dampening of 10 m^2S already have a short reverberation time and is not really needed for further dampening unless as in this case it is for a bedroom. In a bedroom most of the absorption area is located to the bed, which means it is not spread evenly on all areas, as the formula assumes. This means that it could probably be of use to put in a few sound absorbing wall panels to actually dampen the sound in the room. This will most likely enhance the perception of the sound conditions in the room.

In BBR the demands for a bedroom are set to a sound pressure level of 30 dB. Different scenarios were set according to sound pressure level. One of the scenarios where the current sound pressure level was 33 dB in a normal dampened room were calculated. To lower the sound pressure level by 3 dB we would need to put in 7 wall panels of the dimensions 1.2 m^2 to achieve a quiet bedroom. In a room with a total wall area of 35 m^2, this is almost 25% of the total wall area.
For a bedroom with a lot of disturbing noise from the traffic, from ventilation and from neighbours, structure-borne noise, a sound absorber doesn't make that big of a difference. This type of sounds needs to be removed by sound insulating which is achieved when constructing the building. But by lowering the sound pressure level by 3 dB actually makes an audible difference to a regular person. Especially in a bedroom where most of the absorption area is located to the bed, it could make a good difference in how the sound will be perceived.

By just lowering the sound pressure level by 1 dB, might not be audible to a regular person, but it can still make a difference even in a bedroom when it comes to experience and perceiving the sound. Also the fact that the environment plays a big role for how we perceive the sound it will have effect if the room is furnished with a lot of absorbing materials and textiles to make it more comfortable and cozy. Just by knowing that you put in curtains that are sound absorbing and also knowing that you put a sound absorbing wall panel on the wall will probably have a bigger effect than the actual numbers from what these calculations show.

This type of absorbers might give a bigger effect in rooms that don't have as much absorbing materials, as kitchen for example. Kitchen has a higher sound pressure level of 35 dBA and 40 dB, due to the facts that there are a lot more hard reflective areas and usually kitchens have more of the hard unwanted sounds. This means that the sound will have a longer reverberation time and also this room is not used for resting in the same way as bedrooms. The wall panels might also have a bigger effect in living rooms which usually have larger areas and where the perception and experience of sound is more important.

For the comparison of sound classification this thesis has some limitations. According to standard SS EN ISO11654, this comparison is not applicable if not the whole frequency range is met as the frequency range for the reference curve. Since the measurements in this thesis only have a range of 0-1500 Hz the result is not entirely reliable and should need complementary tests to add more value to the measurements and give it the whole width of frequencies that is needed according to standard. These complementary measurements are also to be done in a impedance tube, but in a tube with much smaller diameter to reach the higher frequencies. This sound classification is also built on diffuse sound source and in a impedance tube the sound source comes perpendicularly in to the test objects. Such comparison can be applicable if the material is homogenous, but textiles as one of the materials used in these tests are not homogenous in all angles.

7.2 Conclusion

Let us look back at the questions asked in the beginning.

- Is it possible to manufacture a sound absorbing wall panel, for home environment?
- Could the sound pressure level in a room be decreased by 3 dB?
- Could the reverberation time be decreased to 0.3 s?
- Is it possible to attain a sound classification C by only using textiles?
- Meanwhile maintaining a low product price and environmental awareness?
-

To sum it all up this project shows that it is possible to achieve a classification C with only textiles even though it in this case means two different materials in double layers. To manufacture a sound absorbing wall panel for homes and to use the materials used in "Blue+4", which is a polyester knitted fabric in combination with a polyester nonwoven batting of a total depth of 50 mm, it is possible to lower the sound pressure level with 3 dB in a normal dampened bedroom. According to the calculations made this wall panel could also decrease the reverberation time to 0.3 s which is a more suitable level of reverberation time for bedrooms. This combination also resulted in a $\alpha_w = 0.7$, which is within the higher range of sound classification C. In this project it was also found that the demands of a sound classification C surprisingly could be reached by only textiles, but due to fulfil the remaining demands set to this project, as price and environmental awareness, the materials chosen to proceed with included a polyester fabric and also a polyester nonwoven.

7.3 Future works

For further research it would be interesting to knit or weave fabrics with different properties but in the same material to see if it's possible to reach a classification C, but with only textiles with only one material and preferably a material that is recyclable or maybe biodegradable. If we look at the wall panels available at the market today they are often made from wool or polypropylene (PP), wool is expensive but to use PP might be cheaper to manufacture.

It would also be interesting to do a price calculation to see at what price range this product could be produced within and to do more research on how this product could be more environmentally friendly, recyclable or produced from recycled polyester or waste material.

To further calculate and see how the wall panel could affect the reverberation time and sound pressure level it would be interesting to use the program CATT Acoustics to get a more precise calculation than the ones made with Sabine's formula. Sabine's formula assumes that there is a diffuse sound field which is seldom the case for regular rooms. In CATT one can calculate on reverberation time with different types of sound sources as ventilation, traffic and loud speaker and also to place the sound sources in different positions. It is also possible to measure how strong the sound pressure level is at different positions in the room for a receiving person. Unfortunately we didn’t have enough time to complete the calculations in CATT, but it would be very interesting as a further research.

This thesis focused on products for private persons and home environment, but there is also a huge need and possibilities, and money to make for IKEA, for this type of product for their business customers.
Also for both private persons and businesses, it’s not only wall panels that is of interest, it’s also wall hangings, headboards for beds, room dividers, both hard and soft ones, screens to use in open office spaces and so on.
Also to put reliable facts to more products within the IKEA range today, showing that this product has good sound absorbing properties, so that they can be marketed as sound absorbing will give the product an extra value to the customer an also, which often is the case, the sound absorbing property gives the product an energy saving property as well.

8 Referece list

Aizenshtein, E. M. (2012), *Global chemical fibre production in 2011*, Fibre Chemistry, vol. 44, no. 3, pp. 141-145.

Aizenshtein, E.M. (2007), *World production and consumption of polyester fibres and yarn. Status and prospects for the Russian market*, Fibre Chemistry, vol. 39, no. 5, pp. 355-362.

Aizenshtein, EM (2003), *Production and Use Of Polyester Fibres Today and Tomorrow*, Fibre Chemistry, 35, 5, pp. 317-328, Textile Technology Complete.

Albertsson, AC. & Edlund, U. & Odelius, K. (2011). *Polymerteknologi – Makromolekylär design*. Stockholm.

Anonymous, (2012), *Nonwoven Industry to be 20 Percent of Global Textile Industry by 2017*, Man-Made Textiles In India, vol. 40, no. 9, p. 322, Textile Technology Complete.

Coates, M, & Kierzkowski, M 2002, *Acoustic Textiles -- Lighter, Thinner and More Sound-Absorbent*, Technical Textiles International, 11, 7, p. 15, Textile Technology Complete.

Belin, P., Zatorre, R.J., Lafaille, P., Ahad, P. & Pike, B. 2000, *Voice-selective areas in human auditory cortex*, Nature, vol. 403, no. 6767, pp. 309

Beranek, L. 2011, *Concert hall acoustics*, Architectural Science Review, vol. 54, no. 1, pp. 5.

Blauert, Jens. & Xiang, Ning. (2009). *Acoustics for Engineers: Troy Lectures*. Berlin, Heidelberg: Springer Berlin Heidelberg pp 2-3.

Blauert, J. (2005). *Communication Acoustics.* Springer-Verlag, Berlin, Heidelberg.

Bodén, H., Carlsson, U. R Glav, H P Wallin och M Åbom. (2001) *Ljud och Vibrationer*. Institutionen för Farkostteknik/Marcus Wallenberg Laboratoriet för Ljud- och Vibrationsforskning. Nordstedts Tryckeri AB, Stockholm.

Burström, Per Gunnar, 2007. *Byggnadsmaterial* 2. uppl. Lund: Studentlitteratur

Ching-Wen, Lou; Jia-Horng, Lin; Kuan-Hua, Su (2005), *Recycling Polyester and Polypropylene Nonwoven Selvages to Produce Functional Sound Absorption Composites,* 2005, Textile Research Journal, vol. 75, no. 5, pp. 390-394.

Coates, M. & Kierzkowsld, M. (2002). *Acoustic textiles-lighter, thinner and more sound-absorbent*. Technical Textiles International : TTI, vol. 11, no. 7, pp. 15.

Encyclopedia Britannica
http://www.britannica.com/EBchecked/topic/589392/textile [2013-06-06]

Byggros Geotextiles
http://se.byggros.com/Geotextil_-_non-woven (nd). Nonwoven. [2013-05-11]

EDANA
http://www.edana.org/discover-nonwovens/what-are-nonwovens- (nd). Nonwoven. [2013-05-11]

Euceb
http://www.euceb.org/[2013-05-11]

Fletcher, K. (2008). *Sustainable Fashion and Textiles: design Journeys*. Malta: Gutenberg Press.

Gallagher, M. (2008). *Music Tech Dictionary : A Glossary of Audio-Related Terms and Technologies.* Boston, MA, USA: Course Technology / Cengage Learing pp 78, 256, 52.

Heylighen, A., Rychtáriková, M. & Vermeir, G. (2010). *Designing spaces for every listener*. Universal Access in the Information Society, vol. 9, no. 3, pp. 283-292.

Highfiled, D. (2000). *Room Acoustics.* Florence, KY, USA: Routledge pp 362.

Hörselskadades riksförbund (HRF): *Kakofonien: en rapport om störande ljud och samtalsvänliga ljudmiljöer*. (2009). Stockholm: Hörselskadades riksförbund (HRF)

Humphries, M., 2009, fourth edition. *Fabric Reference,* Pearson education, Inc., Upper Sadler River, New Jersey 07458

IKEA
www.ikea.com [2013-06-06]

Kleiner, M. (2003). *Audio Technology and Acoustics.* Chalmers, Gothenburg

Kosuge et al., 2005, Lou et al., 2005, Shoshani and Yakubov, 1999, Shoshani and Yakubov, 2000, Shoshani, 1990 and Shoshani and Wilding, 1991. Jiang, N., Chen, J.Y. & Parikh, D.V. 2009, "Acoustical evaluation of carbonized and activated cotton nonwovens", *Bioresource technology*, vol. 100, no. 24, pp. 6533-6536.

Liu, Yanping; Hu, Hong, (2010). "Sound Absorption Behavior of Knitted Spacer Fabrics", *Textile Research Journal,* vol. 80, no. 18, pp. 1949-1957.

Moholkar, V.S. & Marijn, M. C. W. *Acoustical characteristics of textile materials.* Textile Research Journal, vol. 73, no. 9, pp 827.

Møller, H. & Pedersen, C.S. 2004, "Hearing at low and infrasonic frequencies", *Noise & health,* vol. 6, no. 23, pp. 37-37.

Möser, M. 2009, *Engineering Acoustics: An Introduction to Noise Control,* Springer Berlin Heidelberg, Berlin, Heidelberg, pp. 1. 221-222.

Nationalencyklopedin
http://www.ne.se/sok?q=ljudvåg (nd). Ljudvåg. [2013-05-11]

Nationalencyklopedin
http://www.ne.se/sok?q=oktav (nd). Oktav. [2013-05-11]

Nationalencyklopedin
http://www.ne.se/akustisk-impedans (nd). Akustisk Impedans. [2013-05-11]

Nationalencyklopedin (2013).
http://www.ne.se/textilier (nd). Textilier. [2013-05-02]

Passero, C.R.M. & Zannin, P.H.T. (2010), "Statistical comparison of reverberation times measured by the integrated impulse response and interrupted noise methods, computationally simulated with ODEON software, and calculated by Sabine, Eyring and Arau-Puchades' formulas", *Applied Acoustics,* vol. 71, no. 12, pp. 1204-1210.

Snidare, U. 1994. *Tyger , Inred med Svenska Textilier*, Bonnier Alba. ISBN 91-34-51534-8

SP Sveriges Tekniska Forskningsinstitut
http://www.sp.se/sv/index/information/fireclassification/sidor/default.aspx [2013-04-24]

Streitberger, E. (1991), *The Inverse Square Law,* The Science Teacher, vol. 58, no. 6, pp. 87.

Svensk Standard (2003). *SS*-ISO 354:2003 Acoustics –Measurement of sound absorption in a reverberation room(ISO 354:2003), Stockholm: SIS

Svensk Standard (1997). *SS*-ISO 11654:1997 Acoustics - Sound absorbers for use in buildings - Rating of sound absorption(ISO 11654:1997), Stockholm: SIS

Svensk Standard (2009). SS-ISO 25267:2004/T1:2009 Acoustics – Sound classification of spaces in buildings – Dwellings, Amendment 1 (ISO 25267:2004/T1:2009), Stockholm: SIS

Svensk Standard (2007). *SS*-ISO 25268 Acoustics - sound classification of spaces in buildings - institutional premises, rooms for education, preschool and leisure-time centres, rooms for office works and hotels, Stockholm: SIS

Tillberg, K. 2012, *The use of Textiles in an Acoustic Context.* Lic., Department of Civil and Environmental Engineering Division of Applied Acoustics, Vibroacoustic Group Chalmers University of Technology Gothenburg, Sweden.

Velu Y. K.; Ellison M. S.; Dai J.; Rogers C. D. (1999) "Single Fiber Acoustic Emission and Tensile Properties from Cotton Bundle Fracture Tests". *Textile Research Journal,* Aug. Vol. 69 Issue 8, pp 616-629.

White, Glenn D. Louie, Gary J. (2005). *Audio Dictionary (3rd Edition).* Seattle, WA, USA: University of Whasingtin Press pp. 518.

Wikipedia
http://en.wikipedia.org/wiki/Composite (nd). Composite. [2013-05-11]

Zetterblom, M., 2011. *Textile Sound Design*. Diss., Department of Applied Information Technology, Chalmers University of Technology, Gothenburg Sweden.

Zilenzio
http://www.zilenzio.se/foretaget.aspx [2013-05-17] [2013-06-06]

Åkerlöf, L. 2001, *Byggnadsakustik*, AB Svensk Byggtjänst, Elanders Svenskt tryck AB, Stockholm.

Yang, S., Yu, W. & Pan, N. (2011). *Fractal phenomenon in sound absorbing behavior of down fiber assembly*, Textile Research Journal, vol. 81, no 11, pp. 1139-1144. 2011

Yogeshwar K. Velu, Michael S. Ellison, Jinrong Dai, Clarence D. Rogers, *Single Fiber Acoustic Emission and Tensile Properties from Cotton Bundle Fracture Tests*, Textile Research Journal, 1999

9 Appendix

9.1 Appendix 1

Test results from Kundt's tube meassurements.

Figure XXI. The result from Kundt's tube in one third octave band.

Freq. (Hz)	Batt5 Alpha	Batt4 Alpha	Batt3 Alpha	Batt2 Alpha	Batt1 Alpha	Multi Alpha
100	0,09	0,20	0,08	0,12	0,08	0,39
126	0,10	0,21	0,08	0,14	0,09	0,38
158	0,13	0,25	0,11	0,16	0,10	0,33
200	0,16	0,28	0,13	0,13	0,09	0,31
251	0,18	0,34	0,16	0,33	0,12	0,32
316	0,25	0,40	0,21	0,50	0,13	0,53
398	0,38	0,48	0,26	0,59	0,13	0,65
501	0,50	0,65	0,32	0,66	0,15	0,82
631	0,61	0,76	0,41	0,74	0,17	0,90
794	0,74	0,86	0,52	0,79	0,20	0,94
1000	0,86	0,95	0,64	0,80	0,25	0,86
1259	0,94	0,99	0,76	0,80	0,31	0,78
1585	0,99	0,99	0,85	0,80	0,36	0,75

oktavband	Batt5	Batt4	Batt3	Batt2	Batt1	Multi
125	0,10	0,22	0,09	0,14	0,09	0,36
250	0,20	0,34	0,17	0,32	0,11	0,39
500	0,50	0,63	0,33	0,66	0,15	0,79
1000	0,85	0,93	0,64	0,80	0,26	0,86

Freq. (Hz)	Back&White Alpha	Blue Alpha	Blue+5 Alpha	Blue+multi+5 Alpha	Blue+4 Alpha	Blue+2 Alpha
100	0,38	0,43	0,27	0,31	0,21	0,28
126	0,32	0,37	0,28	0,31	0,24	0,29
158	0,29	0,31	0,30	0,33	0,29	0,32
200	0,27	0,25	0,33	0,43	0,34	0,32
251	0,28	0,23	0,38	0,56	0,42	0,36
316	0,43	0,22	0,43	0,63	0,51	0,60
398	0,54	0,23	0,55	0,70	0,59	0,65
501	0,75	0,26	0,69	0,72	0,73	0,70
631	0,94	0,34	0,80	0,73	0,83	0,74
794	0,99	0,45	0,90	0,73	0,91	0,79
1000	0,92	0,58	0,97	0,69	0,96	0,79
1259	0,84	0,71	0,99	0,67	0,96	0,80
1585	0,78	0,79	0,98	0,66	0,94	0,80

oktavband	Back&White	Blue	Blue+5	Blue+multi+5	Blue+4	Blue+2
125	0,33	0,37	0,28	0,31	0,25	0,29
250	0,33	0,23	0,38	0,54	0,42	0,43
500	0,74	0,27	0,68	0,71	0,72	0,70
1000	0,91	0,58	0,95	0,70	0,94	0,79

Figure XXII. The result from Kundt's tube in one third octave band.

	Batt5	Batt4	Batt3	Batt2	Batt1	Multi
Freq. (Hz)	Alpha	Alpha	Alpha	Alpha	Alpha	Alpha
100	0,09	0,20	0,08	0,12	0,08	0,39
126	0,10	0,21	0,08	0,14	0,09	0,38
158	0,13	0,25	0,11	0,16	0,10	0,33
200	0,16	0,28	0,13	0,13	0,09	0,31
251	0,18	0,34	0,16	0,33	0,12	0,32
316	0,25	0,40	0,21	0,50	0,13	0,53
398	0,38	0,48	0,26	0,59	0,13	0,65
501	0,50	0,65	0,32	0,66	0,15	0,82
631	0,61	0,76	0,41	0,74	0,17	0,90
794	0,74	0,86	0,52	0,79	0,20	0,94
1000	0,86	0,95	0,64	0,80	0,25	0,86
1259	0,94	0,99	0,76	0,80	0,31	0,78
1585	0,99	0,99	0,85	0,80	0,36	0,75

oktavband	Batt5	Batt4	Batt3	Batt2	Batt1	Multi
125	0,10	0,22	0,09	0,14	0,09	0,36
250	0,20	0,34	0,17	0,32	0,11	0,39
500	0,50	0,63	0,33	0,66	0,15	0,79
1000	0,85	0,93	0,64	0,80	0,26	0,86

	Back&White	Blue	Blue+5	Blue+multi+5	Blue+4	Blue+2
Freq. (Hz)	Alpha	Alpha	Alpha	Alpha	Alpha	Alpha
100	0,38	0,43	0,27	0,31	0,21	0,28
126	0,32	0,37	0,28	0,31	0,24	0,29
158	0,29	0,31	0,30	0,33	0,29	0,32
200	0,27	0,25	0,33	0,43	0,34	0,32
251	0,28	0,23	0,38	0,56	0,42	0,36
316	0,43	0,22	0,43	0,63	0,51	0,60
398	0,54	0,23	0,55	0,70	0,59	0,65
501	0,75	0,26	0,69	0,72	0,73	0,70
631	0,94	0,34	0,80	0,73	0,83	0,74
794	0,99	0,45	0,90	0,73	0,91	0,79
1000	0,92	0,58	0,97	0,69	0,96	0,79
1259	0,84	0,71	0,99	0,67	0,96	0,80
1585	0,78	0,79	0,98	0,66	0,94	0,80

oktavband	Back&White	Blue	Blue+5	Blue+multi+5	Blue+4	Blue+2
125	0,33	0,37	0,28	0,31	0,25	0,29
250	0,33	0,23	0,38	0,54	0,42	0,43
500	0,74	0,27	0,68	0,71	0,72	0,70
1000	0,91	0,58	0,95	0,70	0,94	0,79

Figure XXIII. Shows the result from Kundt's tube in one third octave band

	Multi+5	2xblue+multi	2xblue+2xmul	4simple	Blue+4simplel	Blue42
Freq. (Hz)	Alpha	Alpha	Alpha	Alpha	Alpha	Alpha
100	0,38	0,44	0,31	0,47	0,19	0,28
126	0,39	0,38	0,29	0,41	0,21	0,29
158	0,40	0,35	0,36	0,36	0,24	0,30
200	0,40	0,33	0,42	0,33	0,28	0,33
251	0,40	0,34	0,47	0,31	0,34	0,38
316	0,43	0,45	0,61	0,33	0,40	0,47
398	0,69	0,58	0,70	0,41	0,52	0,56
501	0,80	0,69	0,69	0,51	0,65	0,71
631	0,72	0,81	0,67	0,63	0,78	0,81
794	0,75	0,85	0,65	0,76	0,88	0,90
1000	0,75	0,86	0,62	0,88	0,96	0,95
1259	0,70	0,85	0,62	0,96	0,99	0,97
1585	0,64	0,82	0,64	0,99	0,97	0,96

oktavband	Multi+5	2xblue+multi	2xblue+2xmul	4simple	Blue+4simplel	Blue42
125	0,39	0,39	0,32	0,41	0,21	0,29
250	0,41	0,37	0,50	0,32	0,34	0,39
500	0,74	0,69	0,69	0,52	0,65	0,69
1000	0,73	0,85	0,63	0,87	0,95	0,94

9.2 Appendix 2

A shorter company presentation of IKEA.

The story of IKEA as we know it, started in the 1920s in in a small village in småland Sweden. The name IKEA is formed from the initials of Ingvar Kamprad, Elmtaryd Agunnaryd. Ingvar Kamprad grew up on the farm Elmtaryd in Agunnaryd, where he began his career as early as at the age of five by selling matches.
However, it took until 1943 before he founded the furniture company that today is a multinational company with 139 000 co-workers in 44 countries and with a resale of over 27 billion euro. The story of IKEA as we know it, started in 1953 when Ingvar bought a carpentry shop in Älmhult, which he made into a showroom for furniture. A few years later he built a furniture hall, which later became the first Ikea department store.
Since August 31st 2012, IKEA has stores in more than 38 countries. The IKEA Group owns a total of 287 stores in 26 countries. All IKEA stores are operated as franchises under contract with Inter IKEA Systems B.V.

IKEA has a vision to create a better everyday life for the many people. Being able to offer a wide range of home furnishing products at prices so low that as many people as possible can afford to buy them. One of the basic ideas for IKEA products is that low prices should also be able to provide functional home furnishing products with attractive design.

It is no coincidence that the IKEA logo is yellow and blue as the colours of the Swedish flag. IKEA calls their approach Swedish; modern, but not too trendy, functional yet attractive. They are striving for a human and child-friendly approach and represent a sound and healthy Swedish lifestyle. Their designers and product developers are working for the products to meet the daily needs without unnecessary details and in the design process is the price tag that is the first thing to be set. Their product line aims to offer solutions for every room, and out of all the styles, whether it is the minimalist or the romance and everything in between.

IKEA wants to protect the people and moral values and thus create opportunities for many. IKEA has something they call the code of conduct, they can not compromise on safety, respect for each other and for the environment. This Code of Conduct also sets the standards for their suppliers and IKEA are doing what they can to support the suppliers so that they can meet IKEA's requirements.
IKEA has a clear environmental thinking and working on developing and improving their production processes and recycling processes. They have clear steps they closely follow that example, functional analysis, where they ask themselves why the product is needed. IKEA is aware that they themselves are part of the environmental problem and is working thus on improving and prevention.

As recently as the 8th of May 2013, the newest IKEA store was opened in Uddevalla, Sweden. Not long after this, on the 3rd of June 2013, a new kitchen line was released in IKEA stores all over Sweden. It’s called METOD and meets all the needs of the entire family.

Source: www.ikea.com

9.3 Appendix 3

A shorter company presentation of Zilenzio.

ZilenZio offers serenity in the form of sound-absorbing design. Zilenzio were founded by Marie Lindqvist-Pahlstad and Jenny Helldén. They are keen that their customers will find a solution that suits their needs. The same solution can function very differently in different types of work environments. Therefore, they will guide their customers well through their catalog and range. The goal is to offer a mix of products that provide the best effect. What is the best solution for you; floor screens or desktop screens? Maybe they need to be complemented by wall panels. ZilenZios trained ears have turned many workplaces into good acoustic environments. Zilenzio are claiming that they know this. Those who met one of Zilenzios salespeople can probably attest that they are really passionate about this.
ZilenZio knows that the demands for sound absorbing products are of great need around the world.
They provide a catalogue with internationally standardized measurements and also results from previous customers and are striving for an office in every Nordic capital. Their vision is a balanced acoustic environment in every workplace.

Zilenzio are aware of the impact on the environment and the need for a purposeful engagement. They have an aim to develop their environmental expertise and promote sustainable development and are dedicated to reducing the company's impact on the environment. They want to educate, inform and engage their employees so they can take responsibility for contributing to improved environmental situation and also dialogue with, and inform, their suppliers and partners about what they want to achieve in the environmental field.

Source: www.zilenzio.se