LUND UNIVERSITY

ACOUSTIC IMPACT OF WORKING FROM HOME

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Engineering Acoustics

Master's Dissertation

DEPARTMENT OF CONSTRUCTION SCIENCES
DIVISION OF ENGINEERING ACOUSTICS
ISRN LUTVDG/TVBA--21/5063--SE (1-105) | ISSN 0281-8477
MASTER'S DISSERTATION

ACOUSTIC IMPACT OF WORKING FROM HOME

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Printed by V-husets tryckeri LTH, Lund, Sweden, May 2021 *(Pl)*.

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Abstract

The outbreak of Covid-19 has resulted in major changes on office work. Many office workers have been almost exclusively working from home for the past year, which has led to different advantages and obstacles for the workers.

A lot of studies have investigated the acoustic environment of offices, to distinguish which sound sources that are the most disturbing. The consequences of disturbing noise for working have also been investigated in several studies. The studies that have examined home environment have not focused on distance working.

This thesis aimed to see how office workers are experiencing distance working with a focus on acoustics. Another question asked in the report was whether measured acoustic parameters had any direct impact on noise annoyance.

31 people with similar working conditions participated in the study. Sound pressure level was measured for one hour at the participants' homes while they were working, along with one-hour measurements at the office. In addition, a questionnaire was sent out to the participants asking questions about living conditions, opinions on distance working and perceived noise annoyance. Correlation analyses were made where both questionnaire responses and measured values were analysed.

The responses showed an almost equal amount preferring distance work and office work, with the neutral options being the most popular. A notable number wanted to continue working from home in a high extent. Some stated that they had redecorated rooms in the purpose of creating home offices since they started distance working. The sound measurement showed no clear correlations with preferred workplace or annoyance, indicating that the character of the noise is more important than the volume. The most impactful variables on overall noise annoyance or change in workplace or work hours were number of family members at home, dwelling size, age and disturbance from general maintenance and construction work.

Distance working will most likely continue to be a big part of everyday life after Covid restrictions are listed, which will require more focus on how to improve acoustical environment at home. Improvement on the study would require more participants and different office environments to see impact from a wider array of variables. Other acoustical parameters could also be added to the measurements.

Keywords: *Distance working, Office acoustics, Indoor sound environment, Noise annoyance.*

Sammanfattning

Utbrottet av Covid-19 har resulterat i stora förändringar på kontorsarbete. Många kontorsarbetare har i princip helt arbetat hemifrån det senaste året, vilket har lett till både nya fördelar och nya utmaningar.

Flertalet studier har undersökt ljudmiljön på kontor, och tagit fram vilka ljudkällor som anses mest irriterande. Konsekvenserna av störande buller har också undersökts i flera studier. Studierna som undersökt hemmiljön har dock inte fokuserat på hemarbete.

Detta arbete hade som mål att se hur kontorsarbetare upplever att arbeta hemifrån, med ett fokus på ljudmiljö. En annan fråga som ställdes i rapporten var huruvida uppmätta akustiska parametrar har en direkt påverkan på bullerstörning.

31 personer med liknande arbetsvillkor deltog i studien. Ljudnivå mättes under en timme hos var och en av deltagarna i deras hem medan de arbetade. Ljudnivån mättes även i entimmes-mätningar på kontoret där de arbetade. En enkät skickades ut till deltagarna med frågor om deras boende, åsikter om hemarbete och om bullerstörning. Korrelationsanalyser gjordes där både enkätsvar och uppmätta värden analyserades.

Svaren visade på en jämn fördelning mellan de som föredrog att arbeta hemma eller på kontor, med neutral alternativ som det mest populära. En tredjedel ville fortsätta att arbeta hemifrån i samma utsträckning som de sedan de började arbeta hemifrån. Ett antal uppgav att de hade gjort om rum till hemmakontor sedan de började arbeta hemifrån. Ljudnivåmätningar visade inga direkta samband mellan var de föredrog att arbeta eller hur mycket de störde sig på buller, vilket tyder på att typen av ljud är mer betydande än ljudvolymen. De mest avgörande faktorerna för störning av buller eller förändring av arbetsplats eller arbetstider var antalet familjemedlemmar i hemmet, bostadsyta, ålder och störning från underhålls- och byggarbete.

Hemarbete kommer troligen vara vanligt förekommande även efter Covid-restriktionerna är borta, vilket kommer kräva ett större focus på att förbättra ljudmiljön hemma. Förbättringar av studien skulle kräva fler deltagare och från olika kontorstyper för att tydligare jämföra påverkan från fler variabler. Även andra akustiska parametrar hade kunnat mätas för en utförligare analys.

Preface

What you see before you is the result of a study both made able, but also heavily hindered, by the Covid-19 pandemic. With an interest in room acoustics it felt as the right time to investigate the pandemic’s effect on individual basis, and I was fortunate enough to be able to conduct the research at least somewhat according to original plans. This master was written for the division of engineering acoustics at LTH in collaboration with the acoustics department at Sweco as the final part of the Civil engineering program. The project started autumn 2020 and finished spring 2021.

The two main reasons this study proceeded as good as it did are my two supervisors, who I would like to thank: Nikolaos-Georgios Vardaxis, my supervisor at LTH who contributed with guidance throughout the project, critique when critique was needed, and a vast knowledge in statistics. Also, Kevin Dunne, my supervisor from Sweco, who took charge of the recruitment process, and gave a lot of good ideas for the project as well as making sure the logistics went by as smooth as possible.

Finally, I would like to thank the participants from Sweco, who by agreeing to have sound measurements done at their houses made this study possible. Also, the acoustics department at Sweco deserves my gratitude for helping with the recruitment process and participating in the study themselves.

Christoffer Larm

Lund, May 2021

Notations and symbols

L_p *or* SPL [dB] Sound pressure level

L_{eq} [dB] Equivalent sound pressure level

L_A [dB] A-weighted sound pressure level

L_C [dB] C-weighted sound pressure level

L_{90} [dB] 10th percentile of equivalent sound pressure level

L_{A90} [dB] 10th percentile of equivalent A-weighted sound pressure level

Contents

1. Introduction

1.1 Background

Covid-19 has changed the world in many ways for the past year. Many people have had to change how they work, and distance working has become more of a rule than an exception in certain businesses. In a report by the European Commission (2020) it is stated that it is estimated to be somewhere between 25-40% of the workers in EU who were distance working after the Covid-19 outbreak. This can be compared to numbers from the same report which says that only 5.4% of EU-27 workers usually distance worked, and 9% sometimes distance worked as of 2019 (European Commission, 2020).

With a lot of people working from home it has put the home acoustics in a different perspective. Studies made on sound and noise in dwellings are usually focused on the times that people are at home, and not during the time of day they spend at the office. Home offices are affected by different noises than a regular office, with neighbours making noises, family members being at home or washing machines being used during the day to name a few.

Disturbing noises is an important thing to look at when it comes to working environment. David Sykes (2004) talks about how “Conversational distractions” are the most impactful problems when it comes to reducing worker productivity. Productivity itself is a wide term but can be described as the relationship to what is given to a worker (such as information, equipment, material) and to what is the produced (performed tasks, decisions made, products) (Sykes, 2004). In studies described by Sykes, it was reported that with adjustments to the acoustics in an office environment to decrease disturbing noises and improve the speech privacy, the productivity was improved. Results from the study indicated improvements in focus by 48% along with decreased error rates and physical symptoms of stress on the subjects.

Regular dwellings often lack the usual acoustic improvements that has been made to many offices in recent years, with ceiling absorbers to reduce reverberation and office dividers to both reduce noise and achieve a better feeling of privacy. This is in clear contrast to those distance workers forced to work in an ordinary living room not adjusted for office-like working.

1.2 Purpose and objective

The purpose of this study is to investigate how office-workers perceive annoyance from sound in the office and while working from home. This will give a better understanding of how distance working is affecting work environment during the Covid-19 restrictions and give an insight in how productivity may be affected by acoustical environment. Measurements will be made in addition to a questionnaire to try and determine the most impactful parameters. Along with the acoustics, the study will also try to grasp the general opinion on distance working.

Research questions:

- *How are office workers experiencing distance working in general compared to working from the office?*
- *Is there a correlation between measured sound parameters and perceived noise annoyance?*
- *How are office workers experiencing the sound environment while working from home and how is it affecting their work?*

1.3 Limitations

There are many parameters that could be studied to get a better knowledge of the acoustical environment. Due to limitations regarding time and equipment there will however only be measurements in sound pressure level. The Covid-19 restrictions also prevented from doing measurements within the employee's houses, and instead letting the workers perform the measurements themselves with the help of printed instructions. This meant that the measurements had to be kept simpler than usual to both avoid mistakes and making it feel too troublesome for the participants. Therefore, standard protocol for doing these kinds of measurements had to be set aside in order to make the investigation doable.

The number of participants desired to be able to interpret a statistical result also resulted in several limitations. The questionnaire was made to be as compact as possible while still containing the questions vital for the research in order to get as many responses as possible. Also, recordings were disregarded to not scare away participants due to privacy concerns.

2. Literature review

In a study by Haapakangas et al (2008) it was investigated how employees experienced their acoustic environment, work performance and well-being. The research was made by questionnaires sent out 689 subjects in 11 different companies. 508 of the worked in open offices and 181 in private rooms. Two different enquiries were made, with each version being sent to half of the offices. One asked how often employees were disturbed, and the other asked how much they were disturbed. The study showed that noise was the main source of disturbance, with a higher perceived disturbance than air quality, temperature, and lighting. The study also showed that employees generally were more disturbed by all those sources while working in an open office, with noise giving the biggest difference in disturbance between the two office types.

The research by Haapakangas et al (2008) further showed the sound sources employees tended to be most disturbed by. When focusing on the Open office, the most disturbing source of noise was speech near the workplace. This was the followed by ringing telephones, sound from corridors, doors and elevators, along with speech heard from nearby rooms. 50% of the workers in open offices stated that they were displeased with the acoustics at work, and self-estimations from the workers said that they were wasting about 20 minutes of work every day due to noise. Finally, about 50% of workers in open offices complaining about irritation, exhaustion or concentration difficulties were attributing those symptoms to noise. Haapakangas et al (2008) discusses that the waste of working time cannot be regarded as an exact number, but the study still showed that workers in open offices tended to take extra brakes or working altered times due to too much noise.

In a study by Keränen, Virjonen & Hongisto (2008) it was investigated how changing the characteristics of an office with absorption, sound-absorbing screens, curtains between workstations and increase of masking sound level would reduce acoustic distractions. This was made by four studies, each study altering one of those characteristics. The measured parameters were speech transmission index and A-weighted Speech level. Changed in radius of distraction, spatial attenuation rate of A-weighted sound pressure level of speech, and A-weighted speech level at 4 m from speaker were then calculated. The research was carried out with a sound source producing pink noise, and measurements made at workstations in a straight line from the sound source. Sound-absorptive screens had the most effect on reducing the pressure level of speech, and increased masking sound being the most effective at reducing the radius of distraction. Overall, increased ceiling absorption gave the biggest reduction of disturbance. Keränen, Virjonen & Hongisto (2008) states that reverberation time is not of much importance in an open office, since all changes made in the research, bar ceiling absorption, kept the original reverberation time but improved overall sound environment.

Bergström, Miller & Horneij (2015) conducted a study on how work environment perceptions changed after a relocation from private office to an open office. Questionnaires were sent to employees who were going to be relocated both before the relocation and three follow-ups during a period of 12 months after the relocation. Questions were asked about perceived health, work environment, performance, and work capacity. The ratings of all those answers were decreasing over the time of surveying, and the percentage of employees believing to remain at their current work had decreased from 71% to 41% from before the relocation to twelve months afterwards. Bergström, Miller & Horneij talks about that the perception of health did not have any noticeable differences between the 3-month- and 6-month survey. This could both have to do with a certain level of adaption, and that perception of health could vary depending on which time of the year it is.

A study was made on how different parameters change Speech Intelligibility Index in an office by Bradley (2003). An office was modelled and SII changes simulated when altering office characteristics. A reference office was created that fulfilled the criteria for acceptable speech intelligibility and compared with changes. The most impactful factors to change were ceiling absorption, screen height and office size, while parameters like floor absorption had a very minor improvement. Bradleys study also shows that Speech level and ambient noise have more effect that the room parameters. Finally, he states that an open office often needs to have both a well thought out acoustic environment, along with understanding from the workers side to try keeping the noise levels down in order to get an acceptable speech intelligibility.

In a study by Jahncke (2012) it was examined how an increasing level of background noise would affect worker productivity in an office. Participants were subjected to recorded office noise in both 39 dB L_{Aeq} and 51 dB L_{Aeq}. Memory processes, fatigue, motivation, and signs of stress were examined. The sound played was containing all sounds of usual office noise such as office talk, people walking and ringing phones. The results showed that the participants were mainly worse at memory-based tasks when exposed to a higher sound level. Jahncke suggests this could be due to short exposure times (2 hours) and that test subjects might push themselves a bit extra while doing logical test in an experiment. The study by Jahncke (2012) did, however, see that there was a significant difference in fatigue and motivation when the equivalent sound pressure level was increased. Jahncke also states that there were no measurable differences in signs of psychophysiological stress between the two tests. A second study was made to compare participants with and without hearing loss. The conditions were similar, but the sound levels were now 30 dB L_{Aeq} and 60 dB L_{Aeq}. Results from this study showed that those with impaired hearing were more disturbed by higher noise levels than those with normal hearing and were worse at remembering texts they had read and to recount words in a specific order.

Another study on how background noise affects working was made by Errett, Eileen Bowden, Choiniere, & Wang (2006). The study investigated if different background noises would reduce performance over time. Test subjects were exposed to different levels of background noise over various time durations with the longest sessions being 4 hours. The subjects were tested in a total of 38 hours and were asked to complete math test along with typing tests and verbal reasoning. Enquiries were also handed out to see how the subjects perceived the sounds they were subjected to. Errett et al concludes that there was no trace of correlation between the average rate of correct answers and time the subject were exposed to sound. There was, however, a noticeable difference in how well the subjects performed based on how annoying they perceived the noise.

Banbury & Berry (2005) conducted an investigation on how employees in an open-plan office felt they were disturbed by noise. Questionnaires were handed out to employees at two different companies, and the ambient noise level was measured at both sites instantaneously. Sound measurements were taken in different parts of both offices and a mean value was used. The questionnaire examined disturbance from different sound sources, such as ringing phones, office talk, printers and external sources, and had the participants grade their perceived disturbance on a 5-point scale. The research by Banbury & Berry showed that more than 50% regarded at least one of the eight sound sources as very disturbing, with all but one participant having complaints about at least one of the sound sources. The most disturbing sources was phones ringing from empty desks. The study also looked at correlations between disturbance and time spent at the office and for how long the subject had worked at the office. No correlations were found to indicate that the level of disturbance would decrease with time, and possible habituation was dismissed.

How often employees are disturbed by certain noises was investigated by Sundstrom, Town, Rice, Osborn, & Brill (1994). A questionnaire was handed out to employees working at offices that should be relocated or renovated 6-8 weeks later, and the same kind of questionnaire was then handed out a few months afterwards. Two questions were asked about eight different sound sources: How often do you hear this, and how often does this bother you? Both these questions were answered on a scale of 1-5, where 1 was never and 5 often. An average value for disturbance by the specific sound source was then taken from the two questions, with unreasonable answers ruled out from the analysis (like a noise never heard but often bothering). Questions were then asked about environmental- and job satisfaction. The result from the surveys showed that 54% of the total 2391 employees asked was often bothered by at least one of the sound sources, with telephone noises being the most disturbing followed by talking.

To further investigate how the occurrence of disturbing noise affected the workers, a short survey was also handed out to the supervisors to try find a correlation between disturbance and performance. (Sundstrom et al, 1994). The study showed no clear correlation between performance and disturbance, but the results did show that often disturbing sounds decreased the overall attitude toward the environment- and job satisfaction. The study also showed that most of the sources investigated were often bothering some workers, but that very few workers were often bothered by more than two different sources. Sundstrom et al states that this indicates that an individual often is disturbed by a few very specific noises, but those noises might not be what is generally most disturbing when considering the whole office. There were also some noises that had correlation with environmental satisfaction but not job satisfaction (e.g. people talking) and vice versa.

Noise levels from neighbouring apartments were studied by S.H. Park, P.J. Lee, & B.K. Lee (2017). Apartments with a concrete structure were investigated with 24-hour measurements of sound pressure level. The measurements were done while the residents were not within the dwellings. The microphone was placed at a sitting position in the living room and recorded sounds that exceeded 30 dB L_{Aeq}. $L_{Aeq,1min}$ and L_{AFmax} were calculated and analysed. Of the recorded sounds, 86.5% were structure-born, with movement of furniture, dropping objects and children running being the most frequent. The study looked at recommended values of 35 dBA L_{Aeq} during the day and 30 dBA L_{Aeq} during the night. The results were that these recommended values were exceeded 11% of the daytime and 37% of night-time. Most noise occurrences in daytime were during the time 07-10 in the morning and around lunchtime. S.H. Park, P.J. Lee, & B.K. Lee suggests a long measurement time is needed to get a good understanding of the acoustic conditions in a dwelling.

3. Theory

3.1 General acoustic theory

3.1.1 Sound pressure level

Sound has two characteristic values: frequency and pressure. The frequency determines the pitch of the sound, with a high frequency perceived as a high pitch and a low frequency as a bass tone and is measured in Hertz [Hz] (Nilsson et al, 2008). The pressure is what determines the strength of the sound and is measured in Pascal [Pa]. The sound pressure that can be experienced by humans lies in the area between 10 µPa and 60 Pa. Due to the big spectrum it would not be useful to use a linear scale to illustrate sound pressure, and therefore a logarithmic scale was used to describe sound pressure level (Nilsson et al, 2008). Sound pressure level, L_p, is calculated as:

$$L_p = 10log\frac{\tilde{p}^2}{p_{ref}^2} \text{ [dB]}$$

The reference pressure, p_{ref}, is equal to 2×10^{-5} Pa, which is the threshold of hearing for a human ear in the frequency of 1000 Hz (Nilsson et al, 2008). When doing measurements, it is often useful to get more than an instantaneous value and see how the sound level is over a time period. In those cases, an equivalent sound pressure level, $L_{eq,T}$, is calculated. The equivalent sound pressure level will give a logarithmic average of sound pressure over time. A constant sound over a specific time will result in equivalent sound pressure level and instantaneous sound pressure level to give the same value (Nilsson et al, 2008).

$$L_{eq,T} = 10log\left(\frac{1}{T}\int_0^T \frac{p^2(t)}{p_{ref}^2}dt\right) = 10log\left(\frac{1}{T}\int_0^T 10^{L_p(t)/10}dt\right)$$

3.1.2 Human hearing

As previously mentioned, a human ear can acknowledge sounds with a pressure of 2×10^{-5} Pa at 1000 Hz. This corresponds to 0 dB, and the logarithmical scale means that an increase with approximately 3 dB will double the sound pressure. The sounds a healthy human ear can hear lies in the area of 20 Hz to 20 kHz (Fastl & Zwicker, 2007). The acknowledgeable frequency area is reduced with age, and mostly the higher frequencies are affected by loss of hearing (Nilsson et al, 2008). How high the sound level must be for a sound to be heard or to be a danger for hearing damage depends on the frequency. Figure 1 shows how the thresholds of pain and hearing varies with the frequency of the sound. As can be seen in Figure 1, the threshold of hearing lies around 60-70 dB for very low-frequent sound, and even below 0 dB for frequencies around 3-4 kHz. The threshold of pain is around 120-130 dB with the “limit of damage risk” indicating risk of hearing damage with longer exposure times.

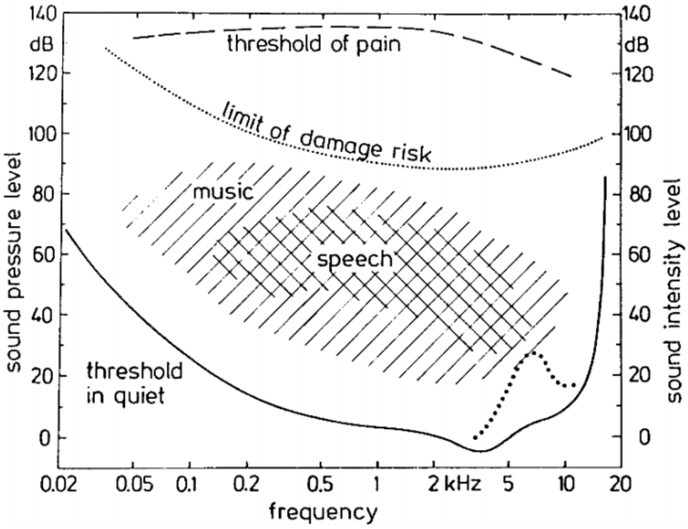

Figure 1. Human Hearing area (Zwicker & Fastl, 2007).

Equal-loudness contours have been developed to indicate how the perception of sound level varies with the frequencies (Nilsson et al, 2008). These lines, as shown in Figure 2, indicates what sound pressure level a sound must be in a certain frequency to be experienced as equally loud in a different frequency. These lines are in the unit phon, which is a psychoacoustical parameter and scaled after experimentation based on subjective hearing (Physclips, 2020). When looking at for example the 40 phon curve, a sound of 40 dB at 1000 Hz is perceived to be as loud as a sound of 90 dB at 20 Hz. An increase in sound pressure level by 10 dB is often perceived as a sound that has doubled in strength by a listener (Physclips, 2020).

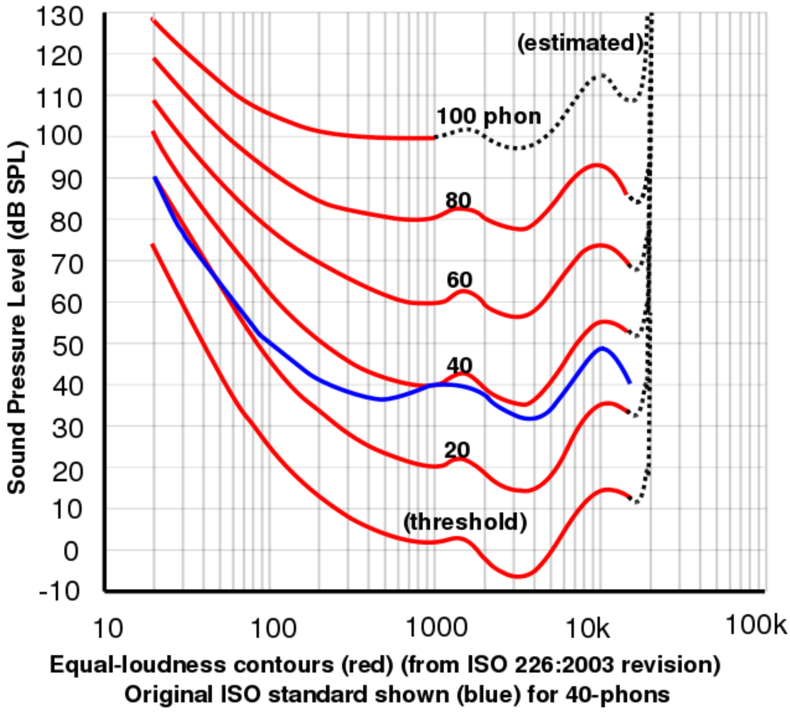

Figure 2. Phon curves for different sound pressure levels (Houser et al. 2017).

3.1.3 Weighting scales

Along with measurements and calculations done to get sound pressure levels from certain sounds, there are weighting-scales which are often used. The weightings are a way to get a more subjective result from the measurement and focus on how humans experiences sound of different frequencies (Nilsson et al, 2008). Figure 3 shows 4 different weightings, with A being the most used, while B and D rarely sees any usage at all (Houser et al, 2017). A-, B- and C-weightings are based on inversions of the equal-loudness contours of 40, 60 and 80 phons respectively while the D-weighting's primary usefulness is while measuring noise from aircrafts (Nilsson et al, 2008). Due to the human hearing, the A-weighting is most used in common measurements and focuses more on sound of mid-frequencies. C-weighted values can be used when there are more sounds of lower frequencies, for example when measuring background noise from a fan (Boverket, 2014).

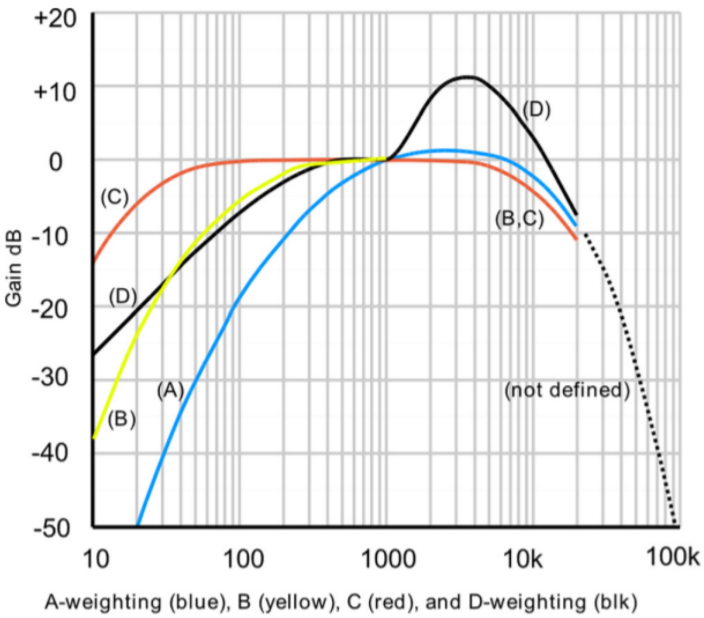

Figure 3. Weighting functions for sound levels (Houser et al. 2017).

3.1.4 How different sounds are perceived

Humans perceive sound in different ways due to a vast number of reasons. Even when focusing on noise there is a big difference in what noises that are considered disturbing and not (Hygge, Kjellberg & Landström, 2013). Sound in the background that contains a lot of information, such as speech for example, will automatically make a human brain try to analyse the information, thus making it harder to perform other analyses at the same time (Hygge, Kjellberg & Landström, 2013).

Predictability and controllability are two important factors when it comes to perceived annoyance (Hygge, Kjellberg & Landström, 2013). If the noise source can be seen but not altered the noise is usually more frustrating, and irregular noises that come without forewarning are more often a cause for loss of focus. Attitude towards the sound and current tasks are also affecting perceived annoyance. If a person perceives the overall environment to be good, the acoustic environment is also often perceived better. (Hygge, Kjellberg & Landström, 2013). The same goes for a sound source; if the sound comes from a source that the listener has a positive attitude towards, then the disturbance is usually lower. When it comes to tasks, noise is often perceived as more annoying when performing complex work than doing something repetitive and easy-going. Finally, it is also a significant difference between persons when it comes to sensitivity, usage to the sound and concentration spans on how sounds are perceived (Hygge, Kjellberg & Landström, 2013).

3.1.5 Effect of noise and sound disturbance

Noise makes it harder to hear and understand speech. The background noise does not need to be very loud to disturb a conversation, especially for those with hearing loss (Arbetsmiljöverket, 2019). Concentration and learning are affected by noise, especially while doing complex tasks. A person subjected to noise while doing complex tasks usually results in a worse performance or a need to struggle more which will lead to fatigue (Arbetsmiljöverket, 2019).

Everyday noise is also a big health problem when looking at different aspects than learning and concentration. One of the most impactful effects of noise is loss of sleep (Arbetsmiljöverket, 2019). Even if the noise itself does not wake a person up, it can lead to increase in stress hormones, sped up breathing along with increased heart rate and blood pressure. Loss of sleep due to noise also have several long-term effects such as a higher risk of heart disease (Arbetsmiljöverket, 2019).

3.2 Room acoustics

3.2.1 Reverberation time

Reverberation time is a parameter commonly used in room acoustics. Reverberation refers to the sound that remains in a room a short while after the sound source has stopped producing sound (Alton Everest, 2001). Reverberation time is described as the time it takes for a sound level to decrease by 60 dB in a room. (Alton Everest, 2001). Alton Everest describes reverberation time in Layman's terms as "the time required for a sound that is very loud to decay to inaudibility". A common way to measure reverberation time is to create impulse sound. For example, a starter pistol or a popped balloon can be used to create the sound and a microphone to measure the time it takes for the sound to decay (Pätynen, Katz & Lokki, 2011). It is, however, sometimes hard to create a sufficient sound pressure level in order to get a difference of 60 dB from the background noise, especially in the lower frequencies. The decay time of the first 20-30 dB reduction is the most important to the human ear, and the reverberation time for 20 or 30 dB is often used when lacking equipment to satisfy quality for 60 dB measurement (Alton Everest, 2001). Reverberation time for 20 and 30 dB are often written as T_{20} and T_{30} respectively.

3.2.2 Speech transmission index and the effect of delay

Sound reaching a listener in a room can be divided into direct sound and reflected sound (se Figure 4). Reflected sound is sound that first hits a surface and then bounces towards the listener.

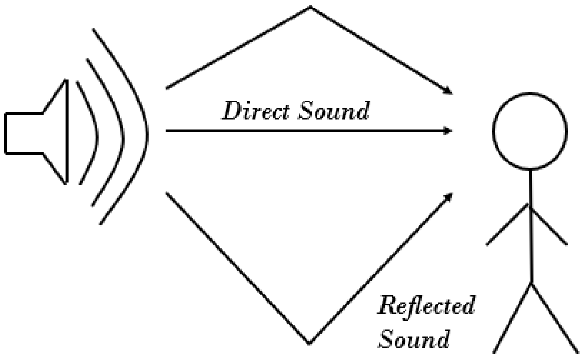

Figure 4. Direct and reflected sound.

The delay of the reflected sound will have a great impact on how easy speech is interpreted. Reflections that arrive to the listener just a short time after the direct sound does not interfere with the intelligibility of the sound, but rather supports it by increasing the loudness (Kuttruff, 2000). The point where the reflection delay is no longer considered helpful is lies somewhere between 50 and 100 ms (Kuttruff, 2000). With long delay it will be harder to interpret the words and syllables are no longer as clear. There are several different ways to try and measure the speech intelligibility in an objective way, with speech transmission index, STI, being one of the most common ones. STI takes several modulation transfer functions into consideration and calculates over multiple octaves (Kuttruff, 2000). Measurement equipment can often measure Speech transmission index without the user needing to do calculations. The speech transmission index will give a value between 0 and 1, with 1 being perfect intelligibility. Values above 0.75 are usually considered very good and values below 0.45 poor or bad (Kuttruff, 2000).

3.2.3 Improvements of office acoustics

When it comes to offices, improvements are often made to enhance the sound environment. Absorbers can be used to lower the overall noise level and decrease reverberation time (Gade, 2011). In offices the roof surface is the most common location to place absorbers, as there is both much free space and low risk of wear damage on the absorbers. Sound absorption can be divided into porous-, membrane- and resonator absorbers. The common porous absorbers reduce the sound with friction between sound in the form of moving air and the surface area of the material (Gade, 2011). The frequencies that can be absorbed is determined by the thickness of the material, which requires thick absorbers to reduce low frequencies. Fabric such as curtains, carpets and furniture also work as porous absorbers, which is the reason to why an unfurnished room will have higher reverberation time (Gade, 2011).

There are numerous guides on how to improve office acoustics with different methods. When targeting specific values, geometry and mathematical models can be used to study how to reach those targets (Kuttruff, 2000). Reverberation time for different frequencies can be approximated fairly simple using different absorption coefficients for the materials and the size of the surfaces (Nilsson et al, 2008). Some companies also have simplified computer models to see how much difference for example ceiling absorbers would to the sound environment using room dimensions and surface materials as input. Auralisation is another way of designing room acoustics. Auralisation are methods to create and simulate a sound environment which is not built. (Kuttruff, 2000). An input signal can be modified using data of the modelled room, and then presented by loudspeakers or headphones to compare different settings.

3.2.4 Some additional parameters for office acoustics

There are a lot of different parameters for room acoustics, with some being more used when examining offices than others. Spatial decay rate is a parameter that is used when looking at the quality of office acoustics. It is a way of quantifying how much the sound is reduced from one workplace to another (Keränen, 2015). The parameter used in ISO 3382:3 (see section 3.4.1 regarding standards) is $D_{2,S}$, which describes the spatial decay rate in A-weighted sound pressure level from speech. A higher value of $D_{2,S}$ will lead to less noise pollution in the office, and therefore a better sound environment (Wenmaekers & Hak, 2015). A-weighted sound pressure level of speech at 4 metres, $L_{p,A,S,4m}$ is another parameter for office acoustics and is based on a single sound source. The radius of distraction, r_D, is calculated as well, and determines the radius for when speech transmission index is reduced below 0,5 (Wenmaekers & Hak, 2015). There are also several different guidelines and ideas for which target values office parameters should have.

3.3 Statistical analysis of data

3.3.1 Confidence intervals and comparison between two categories

When analysing if for example there is a higher mean level of disturbance in the office than at home, two or more groups needs to be statistically analysed. A good way to analyse this would be to use confidence intervals. With large enough samples it is assumed that the confidence interval can be calculated using normal distribution. How many samples needed depends on the distribution, but often can a sample size of more than 30 give a good enough approximation with normal distribution to be considered valid (Vännman, 2015). In order to calculate the confidence interval, the mean value and the margin of error needs to be calculated:

$$CI = \bar{x} \pm \mathrm{t}_{\alpha/2} \frac{s}{\sqrt{n}}$$

Where CI is the confidence Interval, $\bar{x}$ is the mean value, $t_{\alpha/2}$ is a coefficient based on the level of confidence (α), s is the standard deviation and n is the number of samples. This will give a degree of confidence of 1- α (Vännman, 2015).

So, what this means is that if a degree of confidence of 95 percent is wished for, then a coefficient based on that percentage will be used. In that specific case t=1,96. When calculated, the 95% confidence means that based on these samples, there is a 95% chance that the correct mean value given a much larger sample size will be within the interval. This can be used to compare two different intervals, and if those intervals do not coincide, there is a statistical difference between the two samples with a 95% certainty. (Vännman, 2015)

With smaller sample sizes the t-value needs to be determined from a table using probability combined with degrees of freedom (Vännman, 2015). This requires the use of a special method to determine the degrees of freedom when dealing with unequal sample sizes. A method for this is the Welch t-test. This method determines an approximation of the degrees of freedom to use with the easier method called student's t-test (Welch, 1947). The degrees of freedom when combining two samples to investigate if there is a statistical difference between their mean values are calculated as:

$$\mathrm{DoF} \approx \frac{\left(\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}\right)^2}{\frac{s_1^4}{n_1^2(n_1 - 1)} + \frac{s_2^4}{n_2^2(n_2 - 1)}}$$

Where n_i is the number of samples in group *i*, and s_i is the standard deviation of sample *i*.

When using the t-test, results can be grouped into pairs and compared. This is often used with the so-called null hypothesis (Fay & Proschan, 2010). The null hypothesis is a test in statistics with the assumption that something observed is zero. Often this is used to compare two groups, with the assumption that the difference between them is zero. The use of statistical test is to see with what probability the null hypothesis can be rejected (Fay & Proschan, 2010). The t-test will result in a p-value, which determines the probability of the null hypothesis being true. A low p-value will therefore indicate a high chance of there being an actual difference between the two observed groups. P-values below 0,05 are often sought after to indicate a statistical difference, as there can be said to be a difference with 95% certainty. It is usually said in scientific research than p-values exceeding 0,05 does not provide enough evidence to be used as the only indicator of statistical difference (Thisted, 2010). T-test, however, is best when comparing mean values of samples (Fay & Proschan, 2010). There is another method for similar tests called the Mann-Whitney U (or Wilcoxon-Mann-Whitney test) test which can be used when looking at answers that is not justified to be transformed into mean values in the same way. An example of this can be questionnaire questions with a rising scale but that uses wording instead of numbers (Fay & Proschan, 2010).

3.3.2 Correlation analysis using Pearson and Spearman

Doing correlation analyses between variables is a way to see how they influence each other. With a high correlation, an increase in one of the variables will result in an increase or a decrease in the other variable (Boer & Schober, 2018). Correlation coefficients are often presented with the letter r, which can assume values between -1 to 1. Values around 0 means no correlation, positive values a positive correlation (increase in variable a will mean an increase in variable b), whereas negative values mean a negative correlation. r-values of -1 or 1 means a perfect correlation, and that the samples basically can be graphed as a straight line. $|r|>0,7$ is often described as a strong correlation and correlations around 0,5 as moderate correlation (Boer & Schober, 2018). A p-value can also be determined by testing the correlation with the null-hypothesis. A low p-value will in this case indicate that there is a high likelihood that the correlation differs from zero, but does not give information on how strong the relationship is. (Boer & Schober, 2018).

Pearson correlation coefficient uses linear data based on normal distribution and is often the method being used for correlation analysis (Boer & Schober, 2018). However, when the analysed is nonlinear, Spearman's correlation can be used instead. Spearman's correlation is a similar method and will also give an r- and a p-value. The Spearman correlation is preferred over Pearson correlation when values are still being investigated but cannot be considered linear or continuous. This is due to the fact that Spearman correlation uses the ranks of values instead of the values themselves, and is therefore a bit more robust against outliers (Boer & Schober, 2018).

3.3.3 Linear regression analysis

A regression analysis is a model for comparing target values (sometimes called dependent values), usually represented by y, and independent values, usually presented as x. This model could be used to try finding a way to present correlation between target and independent values along with doing predictions of target values. (Chatterjee & Simonoff, 2013). When using a linear regression model for the analysis it is assumed that the measurements will satisfy a linear relationship:

$$y_i = \beta_0 + \beta_1 x_{1i} + \cdots + \beta_p x_{pi} + \varepsilon_i$$

The β coefficients are what makes the function linear and would be called a linear regression even though an x-parameter would be squared (Chatterjee & Smirnoff, 2013). ε represents the error term that separates the actual value from the value in the model, as can be seen in Figure 5, where the margin of error is represented by dotted lines between the model and the values.

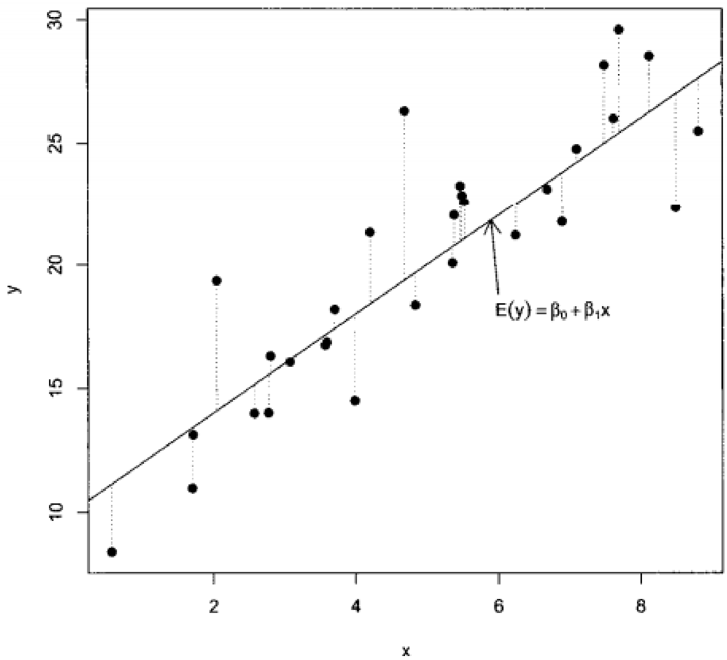

Figure 5. A simple linear regression model (Chatterjee & Simonoff, 2013).

In order to get a model for predicting values that are not measured, the β coefficients needs to be calculated (Chatterjee & Simonoff, 2013). The linear regression equation can be written using matrix and vectors:

$y = X\beta + \varepsilon$, where:

$$y = \begin{bmatrix} y_1 \\ \vdots \\ y_n \end{bmatrix}, \quad X = \begin{bmatrix} 1 & x_{11} & \cdots & x_{p1} \\ \vdots & \vdots & \ddots & \vdots \\ 1 & x_{1n} & \cdots & x_{pn} \end{bmatrix}, \quad \beta = \begin{bmatrix} \beta_0 \\ \beta_1 \\ \vdots \\ \beta_n \end{bmatrix}, \quad \varepsilon = \begin{bmatrix} \varepsilon_1 \\ \vdots \\ \varepsilon_n \end{bmatrix}$$

With the least squares method, the β coefficients can be estimated to give an approximate value, usually represented by $\hat{\beta}$. This can be calculated as:

$$\hat{\beta} = (X'X)^{-1}X'y$$

And the predicted values can be determined as:

$$\hat{y} = X\hat{\beta}$$

The residuals can then be calculated as the difference between actual value and predicted values. The residuals, e, are therefore the error in the prediction model for each observed measurement (Chatterjee & Simonoff, 2013).

$$e = y - \hat{y}$$

The easiest version of the linear regression is when there is just one set of independent values, which is called a simple linear regression (Rawlings, Pantula & Dickey, 1998). This would result in only β_0 as a constant and β_1 which corresponds to the impact given by the independent variable to the equation. When there are several dependent variables it is called a multiple regression analysis, and a β-value is produced for each dependent variable (Rawlings, Pantula & Dickey, 1998). As mentioned in chapter 3.3.1, p-values are used to determine if null-hypotheses can be rejected. p-values can be produced for β-values in a regression analysis as well (Chatterjee & Simonoff, 2013). In a regression analysis, especially when looking at several independent variables at the same time, it is wise to exclude variables that do not contribute to the model. Using the null hypothesis on β-values will show which of the variables that are statistically significant. A high p-value for β will indicate that there is a high probability that the corresponding independent variable does not have any effect on the target value in the model (Chatterjee & Simonoff, 2013)

After doing a regression analysis and determining models with significant variables, correlation is calculated in order to see how well the approximated value fits to the actual values. This can be done by calculating the square correlation coefficient, R^2, where, for a simple regression model:

$$R = \frac{\sum_i (y_i - \bar{Y})(\hat{y}_i - \bar{\hat{Y}})}{\sqrt{\sum_i (y_i - \bar{Y})^2 \sum_i (\hat{y}_i - \bar{\hat{Y}})^2}}$$

The R^2, which also can be called coefficient of determination, will have a value between 0 and 1 and will indicate how good of an estimation the model will give to an actual value (Chatterjee & Simonoff, 2013). Values close to 1 will signal that the model has a good predictability, and a value close to 0 will indicate almost no correlation. The benefit of a square correlation coefficient is that it can look at multiple values at the same time to give a correlation, while the use of just r does not give a clear answer for multiple linear regressions. The linear regression model is in many ways similar to the Pearson correlation coefficient (Boer & Schober, 2018). The regression focuses more on how good you can predict a value based on another parameter, while the correlation analysis determines the strength of the relationship between said parameters. (Boer & Schober, 2018)

When looking at just correlation between two parameters using R, it can be interpreted as a high correlation if R exceeds 0,7. With coefficient of determination that would mean a value above 0,5 (Mukaku, 2009). An R^2 of 50% percent would mean that 50% percent of the actual values can be explained by the regression model (Chatterjee & Simonoff, 2013).

3.4 Standards

There are standardized ways to conduct measurements in an office environment. Here the ISO 3382-3:2012 will be summarized along with Swedish standards which focuses on room-acoustical parameters in an open plan office. ISO 15666 will also be described in short, which focuses on how to create questions for a survey on noise annoyance.

3.4.1 Standards for measuring in open plan offices

ISO 3382-3:2012 is a standard for how to measure acoustic parameters in an open plan office. The calculated quantities from the measurements will mostly report how the speech privacy is in the office. The measurements are made to recreate when one person is talking in the office and the other workers are being silent. Therefore, the measurements are carried out with a single loudspeaker placed in the office. The measurements take place in an office that is empty on people but fully furnished. The preferred measuring positions are at desks in a straight line from the sound source. Only locations between 2 and 16 m away from the loudspeaker can be used for all parameters, and the microphone should be approximately in head height, with a distance of 2 m from walls and 0,5 m from tables. The measurement positions for office desks standing in a straight line is shown in Figure 6. Microphone positions are indicated by the dots placed along line B.

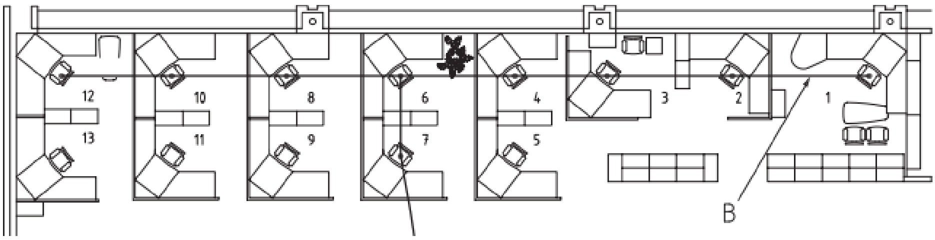

Figure 6. Measurement positions for office acoustics with desks placed in a straight line. (ISO 3382-3:2012).

According to the standard, four measurements should be done at each position. These are sound pressure level in octave bands of pink noise, Speech Transmission Index, background noise level in octave bands and the distance from the loudspeaker. From these four measurements, distraction distance, spatial decay rate, A-weighted SPL of speech, A-weighted SPL of speech at 4 m and average A-weighted background noise are then calculated.

The Swedish standard SS 25268:2007+T1:2017 is another standard regarding office acoustics. This standard is supposed to be used as an addition to the Swedish building regulations, BBR. It has target values for different sound classes (A being the hardest to achieve and D the easiest) regarding air-borne sound, impact sound, room acoustics, SPL from installations and sound isolation from outside sources. The reverberation time, T_{20}, should not exceed 0,4 seconds for classes A-C in an open plan office, and not exceed 0,6 seconds when looking at smaller rooms such as a cell office or a secluded area within an open plan office. The maximum allowed sound level from installations in each class are measured as both A-, and C-weighted L_{eq}. The values for different sound are shown in Table 1. The standard also provides target values for other kind of spaces, such as restaurant, corridors and conference rooms. Similar target values for equivalent SPL from traffic and other outside sources are presented in Table 2.

Table 1. Highest equivalent sound pressure levels from installations in offices

	$L_{A,eq}$ [dB]				$L_{C,eq}$ [dB]			
Type of space	**Sound class**				**Sound class**			
	A	B	C	D	A	B	C	D
Open-plan office	35	35	35	40	55	55	55	-
Cell office/meeting room	30	35	35	40	50	55	55	-

Table 2. Highest equivalent sound pressure levels from traffic and outside sources for offices

	$L_{A,eq}$ [dB]				$L_{C,eq}$ [dB]			
Type of space	**Sound class**				**Sound class**			
	A	B	C	D	A	B	C	D
Open-plan office	35	35	35	40	50	50	55	60
Cell office/meeting room	30	35	35	40	50	50	50	-

For verification, measurements of reverberation time should use the same methods that are presented in ISO 3382. When looking at outside noise, lowest amount of sound isolation should be calculated using outdoor sound pressure levels measured according to SS-EN ISO 16283-3.

For the measurements of installation noise SS-EN ISO 16032 or SS-EN ISO 10052 should be used. SP report 2015:02 (Larsson & Simmons, 2015) is a guideline for measurements of sound pressure levels in rooms using ISO 10052/16032, with 16032 being the technical method and 10052 a more casual approach for the measurements. Three measurement positions should be used, one in a corner of the room and two in random position in the middle of the room. The corner position should be placed in the corner that is least affected by sound absorption, or the corner with the highest measured $L_{C,eq}$ when using the technical method. The microphone should be placed 0,5 meters from the walls with a height of 0,5 if possible. The other two microphone positions should be selected in two random positions in the room 0,75 m from walls, 0,2 m from furniture and at least 1,5 m distance between the two positions. The microphone heights should be between 0,5 and 1,5 m. The measurements for continuous noise should be made with a minimum total of three measurement periods of 30 s. Background level should also be measured for 30 seconds at each microphone position, with the source of noise being turned off. If the difference between background noise and measurements of SPL with the sound source active is less than 4 dB, the background noise is most likely having non-negligible impact on the sound level being emitted from the investigated source.

3.4.2 Standard for questionnaire

The ISO 15666 standard is a guideline on how to formulate questions for a survey on noise annoyance (ISO 15666, 2003). This report suggests that questions on annoyance often are best to formulate in one of two ways. One option is the use of a verbal rating scale to answer a question. The answers are then often formulated from “not at all disturbed” to “extremely disturbed”. Questions with verbal rating often come in 5 options. The other option is to use a numerical scale to answer the level of annoyance one feel. When asking questions about “How much does this sound source annoy you”, a numerical scale of 0-10 is often preferred. It is important not to use any positive/negative numbers, as the definition of noise is that it is unwanted. Therefore, 0 is the answer for no annoyance at all, while 10 is the answer for maximum annoyance.

4. Methods

4.1 Literature review

To begin the thesis a Literature review was made (as seen in section 1.4). Previous research, mainly in office acoustics and sound related to disturbance and loss of concentration was studied. The purpose of the literature study was to find out what was relevant to investigate during the project, and to give a better understanding of the questionnaire design.

4.2 Measurements

Measurements of SPL were be carried out at both homes of workers and at their offices. All subjects were employed at Sweco Malmö and recruited to the study per email. Sound pressure level was measured for one hour with a Norsonic 140 on a tripod with one-second-long intervals at each measurement location. The measurements were made with people working as usual, and therefore measuring the ambient sound value. In order to get a value that represents an ordinary working day as much as possible the measurements were carried out during the times when employees usually are as most productive.

4.2.1 Measurements at dwellings

The measurement at home were performed with the Covid-19 restrictions in mind. To make the measurements as safe as possible, the measurements were carried out by the employees themselves. The measurement devices were brought to the employees' residence and handed to the participant at the front door along with printed instructions on how to operate the device (instructions are presented in Appendix A). Instructions were written in both an English and a Swedish version. The Swedish version was the only one used for the measurements. The device was then collected at the front door after measurements were performed, and thoroughly cleaned with disinfection substance. Measurements were carried out either on the morning (9.30-11.00) or after lunch (13.00-14.30) to try get values that would be as representative as possible for actual work. The employees were also asked to not make any special arrangements to change their sound environment during the measurements. If they usually have family members at home while working, those should not be advised to be quieter than usual to alter the data. The one exception was that people working from home was asked to not play any music from loudspeakers during the time of measurements as it may affect the ambient sound level in such a way that statistical data analysis may be flawed.

The Swedish public health agency, Folkhälsomyndigheten, states in the SP report 2015:2 with guidelines on sound in dwellings and schools that there should be 30 seconds long measurements done in the corner of the least affected by sound absorbents, and two different positions in the room with a minimum distance of 75 centimetres from the walls. In order to make the measurement instructions as easy as possible for the participants, one position is instead chosen, but compensated by doing a much longer measurement. This is also because this study focuses on overall ambient sound pressure rather than just the background noise from installations and traffic. The participants were told to place the measurement device in the same room they were working in, about 2 metres from the working position if possible and not next to any walls or hard surfaces. If the measurement device for logistical reasons could not be placed in a position that matches the instructions, the participants were asked to place the device as close to the centre of the room as possible.

No sound recordings were carried out during the measurements. This choice was made to make it easier to get a lot of test subjects without them declining because of worries about privacy. To get a better understanding of the measurement a few questions were asked to the test subject directly after the measurements had taken place. The point of this is to be able to identify specific outliers in the measurements or to see if there were more background noise than usual because of specific conditions. These questions were be standardized and asked to everyone verbally.

The questions asked were:

- Were there any other persons at home during the measurements?
- Were there any unusual sound sources from outside the dwelling during the measurement?
- Were there any specific sound sources making noise from withing the dwelling?

Reverberation time was not included in the measurements, as it was considered to have too high of a risk of errors for the participants. However, as reverberation time often can be roughly approximated by the furnishment in the room, some participants were asked to take pictures of the setup for the device. This would give a hint on whether they were working in a “normal home condition” or a room with unusually high reverberation time.

4.2.2 Measurements at the office

All participants were working at Sweco Malmö. The building consists of 8 floors, where the top 7 are open plan offices and the first floor is entrance and cafeteria. Figure 7 shows a satellite footage of the building, showing that the south side is not as exposed to traffic as the other sides of the building.

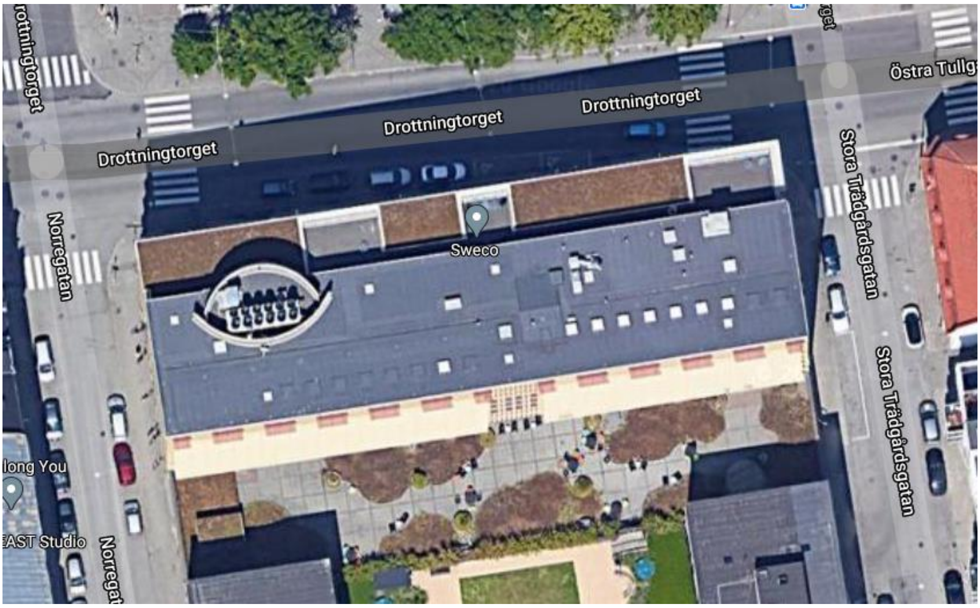

Figure 7. Satellite photo of Sweco office in Malmö (Google maps).

All floors of the building have roughly the same layout, but the number of employees working on each floor has varied significantly during the time since Covid-restrictions started. Because of time limitations it was not possible to measure all floors accurately. A majority of the participants were working on the second floor. The second floor has often seen an occupancy rate of about 10% capacity since November 2020. Parts of the seventh floor has often had an occupancy rate of about 30-40% capacity for the same period. As most of the participants probably would consider the acoustical environment at the office before restrictions when answering the questionnaire, measurements would be conducted both on the second floor and on the seventh floor. The measurements on the seventh floor are conducted to approximate a more representative value of the sound levels that were on the second floor before Covid.

A total of 18 hours of measurement data was collected during a day at the office, using 3 Norsonic140. 8 different zones were chosen for the measurements, using the same zones for both floor 2 and 7. One position was chosen on both short ends of the building, being a bit secluded from the rest of the office. A staircase divides the building in two halves, with the west and east side being fairly symmetrical. Two positions were placed in the northwest, two in the southwest, one in the northeast and one in the southeast. Measurement positions are shown in Figure 8. The same number of measurements were made in the south and north to see if there were any differences between side facing the courtyard and the side facing the road. More measurements were made in the west wing than in the right due to there often being more employees working in the west section on floor 7. Along with these 16 measurements, two hours of data was collected from a meeting room on the second floor with one employee sitting in the room while participating in a video conference (zone 9). Measurements were made between 8.30-11.50 and 13.00-16.20 to measure during the times when employees would be working.

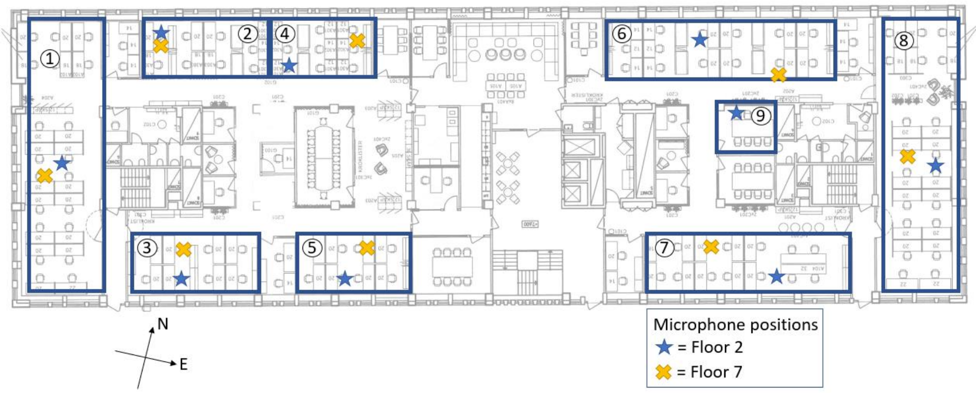

Figure 8. Measurement positions for the office measurements. 9 different office zones are marked and numbered. Microphone positions for floor 2 marked as stars and positions for floor 7 marked as crosses.

The standards and guidelines mentioned in chapter 3.4 were studied, but the procedures were not considered to contribute to the study, as the office measurement should serve as a comparison value to the measurements at home. The microphones were placed in random positions within the chosen zone on a height of 1.3-1.5 m. The positions were chosen to be close to a spot where a person would either sit or stand working on a normal day, an example of a measurement position is shown in Figure 9. Positions also had to be adapted to the people currently working. In each position SPL was measured for one hour.

Figure 9. Norsonic 140 placed for measurement at the office on floor 2.

4.3 Questionnaire

A questionnaire was made using google forms and sent out to all participants per email. The questionnaire design is explained in depth in section *5. Questionnaire design*. The questionnaire asks questions about general work comfort at home and at the office. The main part focuses on acoustic environment, with emphasis on the home environment. This is made to see if there are specific noise sources that disturb more at home, or if there are specific correlations between certain living conditions and perceived annoyance from noise. The questionnaire design is mainly based on previous research mentioned in the literature review, ISO 15666 *Assessment of noise annoyance by means of social and socio-acoustic surveys* and discussions with supervisors.

Both a Swedish and an English version of the questionnaire was produced for the study. The English version used wording from ISO 15666. For the Swedish translation of wording for answers, Vardaxis' doctoral thesis (2019) was used. Vardaxis' research contains a Swedish translation of much of the ISO 15666 developed by Swedish acousticians. The English version was produced in case there were participants who did not understand Swedish well enough, but also for discussion purposes with the supervisors regarding the questions. Only the Swedish version was used in the research.

As the correlation between questionnaire answers and measurement results needed to be investigated, a separate questionnaire link was created for each participant, with the answers being inserted into a document with a code instead of the participant's name.

Along with the email containing the link to the questionnaire, instructions were provided along with information about data handling and a final response date. The contents of this email are shown in appendix B along with the Swedish version of the questionnaire. No English translation was produced for the instructions, since by then it was known that all participants spoke Swedish. The link to the questionnaire was sent out to the participants after measurements had been made at their homes, with the first ones being sent out about 20 days before the final response date. A maximum of two reminders was sent out to the participants who had not responded to the questionnaire, after one week and then two weeks since the first e-mail was sent out.

4.4 Recruitment process

Everyone who participated was working for Sweco during the time of the project, to reduce the amount of office measurements needed and to have the prerequisites as equal as possible. Participants were recruited in two steps during the process, mainly by the acousticians at Sweco. The first part of choosing process consisted of the acousticians contacting other Sweco workers that they know and asking them if they were interested in participating in the project. An e-mail was written for the acousticians to use as a template for project description. The reason contact was made in such a way was that it was considered much harder to get people to volunteer during a pandemic, and the chances of them accepting would be higher if they were contacted by a source they knew personally. The second part, in order to try to increase the number of volunteers, consisted of acousticians sending out group e-mails to co-workers at different Sweco departments.

When workers had stated they were willing to participate they were contacted personally with more detailed information and to set up a date and time for doing the measurements.

Including the acousticians themselves, 20-25 people stated that they were interested in participating. The group e-mails raised this number to a total of 36 participants. 32 measurements were conducted with 4 participants being excluded from the project due to lack of response or due to sickness. 31 of the 32 participants at whose houses' measurements were conducted answered the questionnaire. The measurement of the participant who did not answer the questionnaire was not analysed, which resulted in a total amount of 31 participants to be used for the analysis.

4.5 Data analysis

Firstly, all answers from the questionnaire were presented as histograms to get an overview for the results (some of those are shown in the result chapter, the rest can be viewed in Appendix C). The answers were looked at to see what results might be interesting to investigate in more detail, and what questions that could be excluded from the statistical analysis due to lack of different answers.

The sound measurements were calculated using norXfer. Home measurements were compared to the office measurements, as well as the different zones of the office studied separately. $L_{A,eq}$ and L_{A90} were analysed. L_{A90} (tenth percentile of A-weighted SPL) was considered to represent the background noise, as a measurement of one hour will mean that the L_{A90} almost exclusively shows the values for constant sound.

Correlation matrices were made using Pearson's- and Spearman's correlation analysis. Pearson correlation was used for linear variables and for the questions with answers ranging from 0-10. Spearman correlation was used for all correlations involving a non-linear variable. After the initial tests, some linear variables used as independent values were grouped for a second correlation analysis. For example, when looking at the impact on age, people were grouped into age groups of 30 or younger, 35, 40, 45 and 50+. The mean value for each of these groups was used for the dependant values. This was done as an alternative test to reduce the impact of outliers.

Several linear regression analyses were made to find correlation between both questionnaire answers compared to measurement results, and answers compared to other answers. The regression analyses were made using python code which utilized the scipy-plugin program. For this analysis, questionnaire responses for questions using a rising scale as answers were considered to be linear even if the alternatives were not formulated as numbers. For the simple regression model, R^2 for all different comparisons were presented in a table. Those with $p<0,05$ for the constant corresponding to the independent variable were highlighted. Several multiple regression analyses were made using the same target values and independent variables as in the simple regression analyses. An algorithm was written using python to test all possible combinations of 2, 3, 4 and 5 independent variables. To be able to process the data, regression models where $p<0,05$ for all constants and $R^2>0,3$ were printed from the program. The multiple regression models were then studied in detail to control their credibility.

Python codes using the scipy-plugin program were used to calculate p-values for t-tests and U-tests. Differences in answers and measurement results was compared between for example type of dwelling or whether the respondent had children or not. In order to reduce the risk of using outliers in the result, only groups with a sample size equal or greater than ten was used for these comparisons. Because of this, not all answers for a question could be made into separate groups. The question for dwelling type is an example of this, with the participants living in both terraced house and detached houses being grouped together and compared to those living in apartment buildings. Some of the questions from the questionnaire could not be used in the analysis due only one answer having a sample size great enough for statistical analysis. The results from the different tests were presented in tables using p-values, with some of the comparisons giving low p-values being investigated further.

5. Questionnaire design

The questionnaire of this research is presented in Swedish in its entirety in Appendix B. Both an English and a Swedish version was created to make it easier for participants who were not native Swedish speakers. The Questionnaire was created using google forms, and is in this chapter presented as a more compact version to explain a few choices made for the questions.

The questions asked were mostly based on previous research and standardized questions. ISO 15666 for psycho-acoustic surveys was used to get a better formulation of the questions and how the different answers should be written.

Either a 5-point scale or a 0-10 scale was used depending on the question. 5-point scales were used where it felt more important to use a wording to describe the meaning of each point in the scale. 0-10 scales were mainly used for annoyance or noise levels, as it was considered more useful with a wider range of answers when setting up the regression analysis for those questions.

The questionnaire is titled “A study on sound environment while working from home” (Swedish: “*Studie av ljudmiljö hemma på arbetstid”*). The questionnaire was sent out by e-mail to each participant along with some instructions about the questionnaire and the research. Each participant got a specific link which is used to separate the answers to compare with specific measurements.

The questionnaire is divided into 4 sections. When filling in the form, the participants will only be able to see one section at a time. When a section is filled in, and “next” is pressed, the next section will appear. There is however always a possibility to return and change answers on previous parts. No questions are marked as mandatory, and the questionnaire should take between 10-15 minutes to answer in total. The four sections deal with different types of questions, and are split into:

1. Work-related questions
2. Questions about dwelling
3. Questions about noise
4. Personal questions

The first section is presented in Table 3 and focuses on both were the participants do their work, and what they prefer between working at the office or at home in different aspects of a working place. The first question is asked mainly to see if there are participants who do not work full days, as several studies has indicated that concentration is more affected when doing work over a longer period of time. Questions 2 and 3 are there to see any potential correlation between usage to working from home before and a participant’s feeling on working from home. It also fills a function to see if there are people who still do most of their work at the office now as well.

Questions 4-6 are different aspects of how participants rate working at the office versus at home. These questions are all graded on a 5-point scale. Here office is the description on the left side (1) and at home on the right side (5) on the scale. Consequently, 3 is chosen if the subject is considering both workplaces to be equal in that specific aspect, 1 if the office is considered superior and 5 if working at home is superior. Question 6 is meant to be a mix between the answers in question 4 and 5. The reason to include question 6 is to see if there for example seems to be that people prefer to work at the office even though at home might be more comfortable if they feel they are more productive at the office.

Questions 7 and 8 were added after discussions with the supervisor from Sweco. Even though the building is made up of open plan offices, there are several different rooms that can be used when needed. Some of these rooms are usually occupied by the same individuals for different reasons, and those people could possibly make those workplace changes because of noise.

Question 9 is about how often participants feel disturbed. For this question, participants were asked specifically about when they are in meetings, as that often is one of the times where a worker will feel the most annoyed when disturbed. This is asked with a 5-point scale using descriptions to clarify.

Finally, questions 10-14: Question 10 is formulated as a 5-point question in order to see how much people are changing their hours and routine without going into too specific details about the changes. Questions 11-14 are more specific and related to noise. These questions are not asking about general changes as question 10 does, but rather aims at seeing exactly what sound sources that causes workers to alter their working routine.

Table 3. The first questionnaire section about work

Section 1: Work-related questions

Question	Answering options
1. Do you work full-time?	Yes / No, full days but not all days / No, not full days
2. About how much of your work do you do from home?	Up to 20/40/60/80/100%
3. About how much of your work did you do from home before Covid-19?	Up to 20/40/60/80/100%
4. Where do you feel you get the most work done in a day's work?	A scale of 1 (office) to 5 (at home)
5. Where do you feel most comfortable working environment is?	A scale of 1 (office) to 5 (at home)
6. Where do you prefer to work?	A scale of 1 (office) to 5 (at home)
7. When you are at the office, where do you usually sit and work?	Cell office / Fixed seat / Flexible workspace / Activity-based workstation / Quiet zone / Meeting- or conference room
8. When you are at the office, where do you prefer to sit and work?	Cell office / Fixed seat / Flexible workspace / Activity-based workstation / Quiet zone / Meeting- or conference room
9. If you are in a meeting, how often are you disturbed? **a. At home** **b. At the office**	Not at all / Somewhat / Fairly / Very / Extremely
10. How much have you changed your working hours and working routine in general when working from home?	Not at all / Somewhat / Fairly / Very / Extremely
11. Have you ever changed your working hours because of noise when working from home?	Yes / No
12. If you answered yes on the previous question, what noises caused you to do these changes?	Written text

13. Have you ever changed your working hours because of noise when working at the office?	Yes / No
14. If you answered yes on the previous question, what noises caused you to do these changes?	Written text

Section 2, presented in Table 4, asks questions about the dwelling. Questions 15-23 aims to get a better understanding of the dwelling and the room the participant is working from. The reason both type of floor and floor number is asked in questions 16 and 17 is to get a better understanding of sounds both from the house and from the outside. A middle floor is for example more exposed to sound from neighbours than a top floor. However, there could be a big difference in noise from the outside (roads and courtyards) between an apartment that is located high and an apartment close to the ground, therefore it is not enough to know only what type of floor the participant lives on. Question 22 is mostly there as a comparison question if there are other people living in the dwelling to see how participants want to shut out potential noise from within the dwelling.

Questions 24-28 asks about pets and other people in the household. Potential children's ages are asked to be written down in order to sort out those that can be considered as adults for the study. For example, a child of 16-17 years can usually be considered doing approximately the same types of sounds as an adult.

Table 4. The second questionnaire section about the dwelling

Section 2: Questions about dwelling

Question	Answering options
15. What type of building do you live in?	Apartment building / Terraced house / Detached house
16. On what kind of floor do you work?	Ground floor / Top floor / Middle floor
17. What floor number do you live on? (if you live in an apartment)	Written text
18. What is the size of your dwelling? Answer in square metres	Written text
19. What kind of room do you usually work from?	Bedroom / Kitchen / Living room / Home office / Other (with text)
20. If you answered home office on the previous question, was this room	Yes / No

used as a home office before Covid-19 as well?	
21. What is the size of the room you are working from? Answer in square metres	Written text
22. Do you usually shut the door when working from home?	Yes / No, open door / No, there are no doors to close
23. Does the room have windows that face any of the following: **(More than one can be selected)**	Cycle path / Smaller car road / Main road / Motorway / Train or tram track / Yard or park / Shops or other activity
24. Are there any pets in the household?	Yes / No
25. Including you, how many people live in the household?	Written text
26. How many of these are children, and what are their ages?	Written text
27. Including you, how many adults use to be at home while you are working from home?	Written text
28. How many children use to be at home while you are working from home?	Written text

The third section, presented in Table 5, regards noise. It is explained in the questionnaire that noise refers to unwanted or disturbing sounds as to not create any confusion on the meaning. Question 29 regards noise disturbance in general, and will be one of the main questions to look at when comparing results from different categories based on for example type of residence. Question 30 asks about how often disturbing noises occur, to see if there is any difference between how disturbed a person feel and how often that person is disturbed. It was considered asking this for specific noise sources, similar to the research by Sundstrom et al (1994). It was, however, considered to be difficult to properly analyse that data. It would have resulted in two separate values for each noise source (see question 32 for noise sources) and there were no clear ways on how determine the connection between these values. Such a high number of values would also have required more time for data analysis than would be possible for the project.

Question 31 is asked to see if the participants feel that they are losing productivity due to noise. Haapakangas (2008) asked employees to approximate how much of their working day they lost due to disturbances, but such a question was considered too hard to answer, and would probably need a larger amount of participants in order to get a good approximation.

Question 32, along with the added comment option in question 33, aims to determine which the most disturbing sound sources are. The different sources have been determined through discussion with supervisor and asking other non-participants about what that they are disturbed by during the day. In case some participants are disturbed by very specific noises, question 33 was added to let them describe the source themselves.

Question 34 is asked to see what measures are done to alter the sound environment while working. This could provide useful information on for example why someone is not disturbed by noise while the SPL is high in comparison to other participants.

The section about noise is placed after the question about the office as to not create any bias, specifically towards questions 4-6. Those questions are meant to regard a more general perception, and if the participants have been focusing on determining annoyance by noise before that, the results may be distorted.

Table 5. The third questionnaire section about noise

Section 3: Questions about noise

Question	Answering options
29. How much are you disturbed by noise in general? **a. At home** **b. At the office**	Scales of 0 to 10
30. How often do disturbing noises occur when you are working? **a. At home** **b. At the office**	Not at all / Somewhat / Fairly / Very / Extremely
31. How much do you feel you lose concentration due to noise when working? **a. At home** **b. At the office**	Not at all / Somewhat / Fairly / Very / Extremely
32. How much disturbed are you by noise from the following sources when working from home? **a. Traffic** **b. Maintenance work** **c. Pets**	Scales of 0 (never) to 10 (extremely often)

d. Sound from neighbours **e. Construction work** **f. Sound from courtyard** **g. Ventilation system** **h. Water pipes** **i. Children in the house** **j. Other adults in the house** **k. Household electronics**	
33. Are there any disturbing noise sources that was not provided as an option? In that case, feel free to write the source and a value of disturbance	Written text
34. Do you usually do one or more of the following to shut out noise? **a. Listen to music** **b. Listen to masking noise (white noise, nature sounds etc)** **c. Use any form of hearing protection**	Yes, at home / Yes, at the office / No (both at home and at the office options can be selected)

The 4th and final section of the questionnaire, presented in Table 6, regards personal questions. This is placed last in the questionnaire as to avoid creating unnecessary bias for the other questions.

Question 37 is there to see if there is a difference between if the office or home is preferred workplace based on routine and experience. There might be a difference in opinions between those who were newly educated or new to their occupation shortly before the restrictions started. Question 38 is there to see if there are different opinions from those who worked at Sweco Malmö before they moved into an open plan office. This change in office layout happened around 2014.

Questions 39 and 40 is to see both how means of transportation have changed with the restrictions, and to investigate potential correlation between means of transportation and where they prefer to work. Bike or walking have been combined into one option as the main focus is contact with other people. Both options are deemed to be relatively safe from Covid-infections while public transportation is often avoided.

Question 41 and 42 are asked to indicate both high sensitivity to noise and hearing loss. A high sensitivity would indicate that a person is easier disturbed by most sorts of noise. Hearing loss is an important factor, since people with hearing loss are generally suffering more from a loss of focus and concentration when exposed to the high noise levels over a period of time as a person without hearing loss (Jahncke, 2012).

Question 43 is placed as the last question of the questionnaire since it is the only question that is not about the past or the present. This is more of a general question to see how working from home seems to be regarded, and give an insight in how the balance between working from home and at the office might have shifted due to Covid-19.

Table 6. The last section of the questionnaire, about personal information

Section 4: Personal questions

Question	Answering options
35. Year of birth? Answer with 4 digits	Written text
36. What is your gender?	Male / Female / Other / Prefer not to say
37. For how many years have you been working with your current occupation?	Written text
38. For how many years have you been working at Sweco?	Written text
39. How do you usually get to the office nowadays? (With Covid-19 restrictions)	Car / Public transportation / Bike or walking / I do not go to the office now / Other (with text)
40. How did you usually get to the office before Covid-19?	Car / Public transportation / Bike or walking / Other (with text)
41. How would you describe your sensitivity to sound?	Not at all / Somewhat / Fairly / Very / Extremely
42. Do you use hearing aid?	Yes / No
43. Would you like to work more from home after the restrictions are gone?	Yes, more than now / Yes, as I do now / Either way is okay / No, as before / I do not want to work from home at all

6. Results

6.1 Measurement results

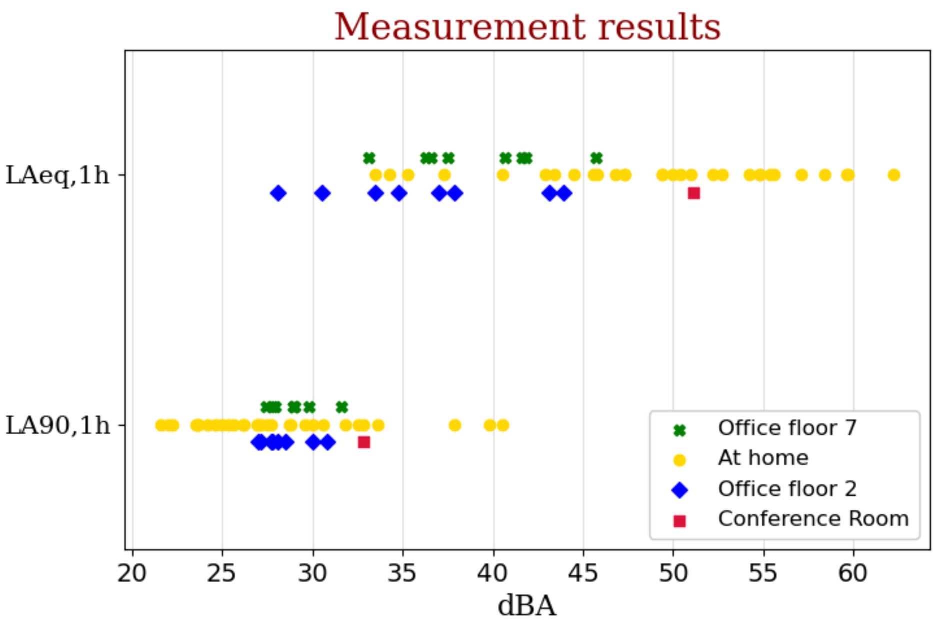

Figure 10. dBA values for $L_{A,eq,1h}$ and $L_{A90,1h}$ for each measurement

L_{Aeq} and L_{A90} for all measurements conducted during the project have been plotted in Figure 10. Measurements for home office (yellow), floor 2 (blue) and floor 7 (green) have been separated. The top half of the graph shows values for L_{Aeq}, with the home measurements varying approximately between 33-62 dBA, while the office measurements are fairly similar between the two floors in intervals around 30-45 dBA. The loudest office measurements were the one done in the conference room, with a significantly higher L_{Aeq} than the other zones. When looking at L_{A90}, the office measurements are in a tight interval, ranging from 27,1 to 31,6 dBA. The levels of L_{A90} are close to the middle of the interval for the home measurements. A lot of the home measurements recorded levels around 25-30 dBA, with some being as low as 22 dBA and a few close to 40 dBA. The home measurements with higher $L_{A,eq}$ had the participants stating that they either were in a meeting for most of the time, had family members or pets at home during the measurement or a combination of these factors.

Figure 11 gives a more detailed view of the results from the office measurements. Floor 2 had the lowest recorded $L_{A,eq}$ in the study, but zones 7 and 8 were completely empty during the time of the measurement. The quietest zone with people working fairly close to the measurement device was zone one on floor two, which is marked as a “quiet zone”. The open office zone with the highest measured values – zone 3 on floor 7 – was also the zone with the most people working there. Also zone 2 on floor 7 had a fairly high occupancy rate but the measured values were lower than most of the other zones with lower occupancy rate. There were no clear connections between measured sound levels and different sides of the building.

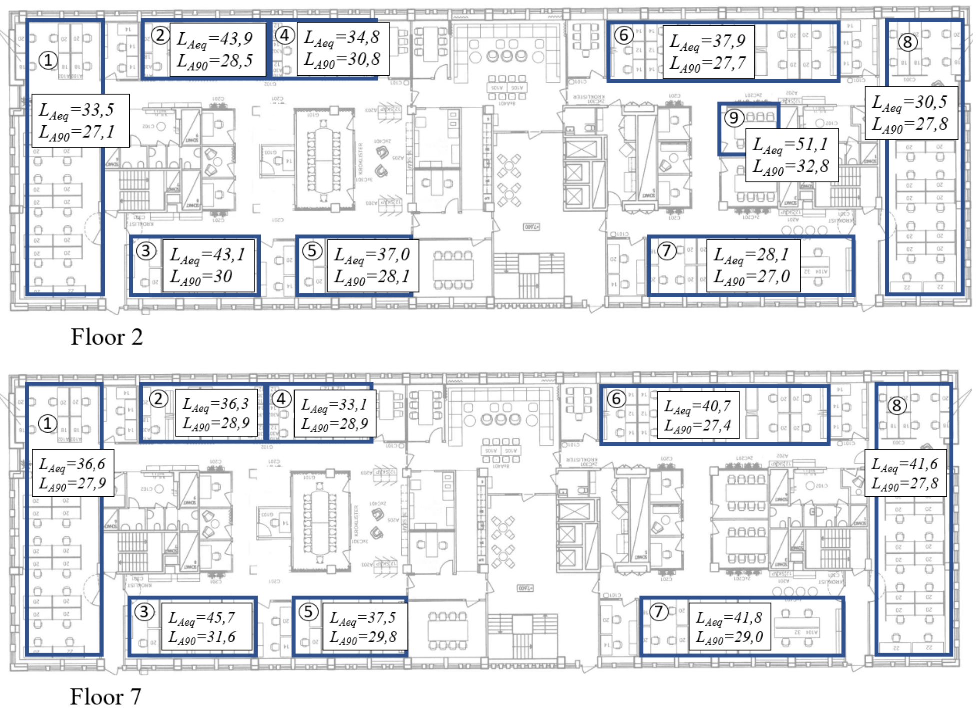

Figure 11. Measured values of $L_{A,eq}$ and L_{A90} in dBA for each measurement zone on floor 2 and 7.

6.2 Questionnaire results

6.2.1 Work-related questions

The first three questions showed that a large majority of the participants worked full time. Almost everyone stated that they had been working 0-20% of their time at home before Covid, and 80-100% as things were when they responded to the questionnaire.

Questions 4-6 were asked as a scale of 1-5, with 1 being office favoured, 5 being at home favoured and 3 as the neutral option. The results from the questionnaire are presented in Figure 12 and show that questions 4 and 6 are normally distributed with the neutral option being the most popular. The answers regarding working environment were a bit more spread out, with a few more of the participants feeling the environment is better at the office.

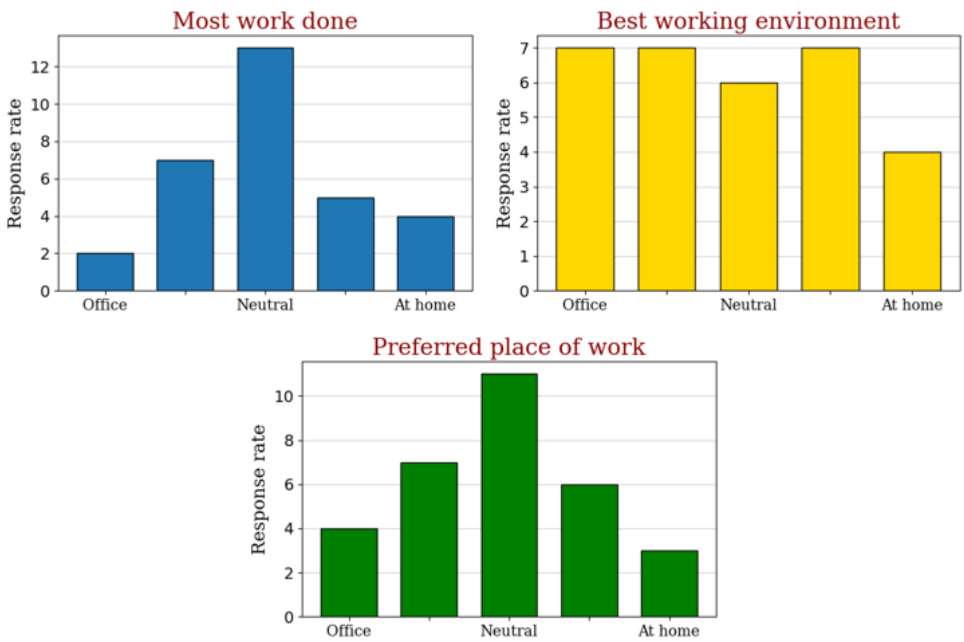

Figure 12. Reponses for questionnaire questions 4 (top left), 5 (top right) and 6 (bottom).

Question 7 and 8 showed that 26 of the 31 participants usually worked in an open space, with flexible workspace and AWB being the most dominant. Figure 13 shows the distribution of where people usually sit and where the preferred position is. 13 of the 31 participants stated that they currently use to work in the position they prefer.

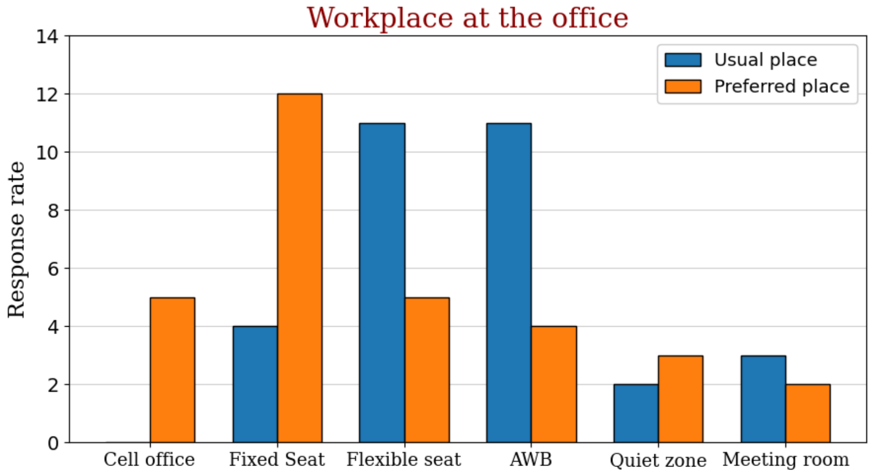

Figure 13. Usual and preferred workplace at the office.

Results from the question regarding how much employees feel disturbed while in a meeting is presented in Figure 14. The answers were fairly similar for home and office. There are, however, a few more of the participants who responded that they were fairly or very disturbed when being in meetings at home, whereas nearly all of the participants said that they were somewhat or not at all disturbed while being at the office.

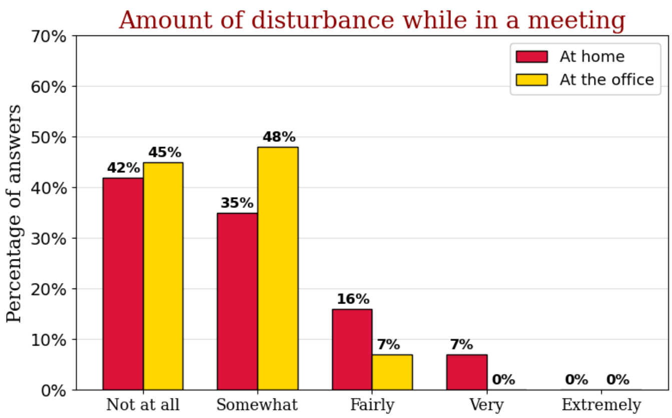

Figure 14. Results from question 9 regarding how much the participants feel disturbed while in a meeting.

For question 10, regarding change in working hours and routine when working from home, 15 participants responded that they had made slight changes to working hours and working routine. 13 participants stated that hours and routines were somewhat changed, 2 answered they had changed very much and 1 answered extreme changes. In the following questions regarding change in working hours specifically due to noise, 10 participants responded that they had made changes in working hours due to noise when working from home. The main reasons were either construction work in their own or a neighbouring house, or other family members making noise. When family members were the cause of change in working hours, adults having work-related meetings or children causing noise when coming home from school seemed to be the biggest distractions. As for working at the office, 7 of the 31 participants had changed their working hours due to noise. Two stated renovations of the office building being the problem, with the rest having trouble with colleagues making too much noise. None of the 31 participants had made any changes in working hours both at home and at the office.

6.2.2 Dwelling-related questions

19 of the 31 participants lived in apartment buildings, 6 in detached houses and 6 in terraced houses. 11 stated that they worked on the ground floor, 12 on a middle floor and 7 on the top floor of the building. The average dwelling size was 97 m^2, with the areas varying between 48 to 220 m^2. The average size of the room the participant worked from was 17 m^2, the smallest being 6 m^2 and the largest being 40 m^2. 12 of the participants (39%) worked from rooms ≤ 10 m^2.

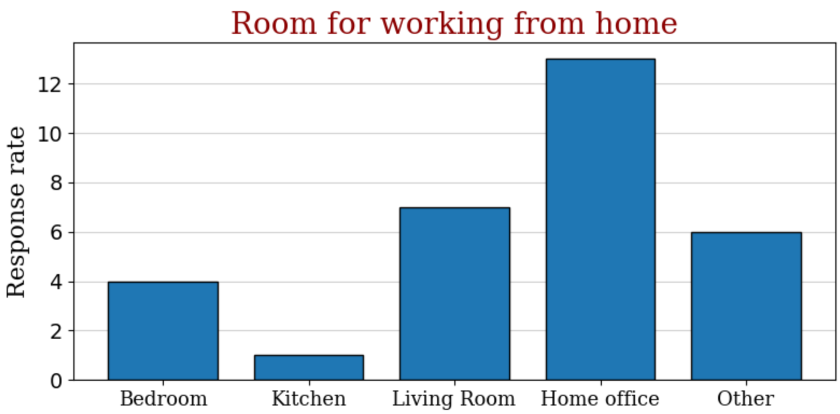

Figure 15. Response rate of which room participants usually work from at home.

Question 19 regarding most usual room for working at home is presented in Figure 15. Rooms designed specifically as home offices were the most frequent, while some of the participants who responded “other” had rooms similar to home offices (hobby room for example) or was using different room types in such an extent that they could not specify a room more common than the others. 6 participants responded that their home offices had been designed as home offices before Covid.

11 of the participants worked with the door closed, 11 chose to have the door open and the last 9 responded that they did not have the option to close any doors while working from home.

Figure 16 shows results from questions 25-28, regarding how many that lives in the dwelling and how many that use to be at home during the day. The average number living in the dwelling was close to two adults and one child. Children at the age of 16 or older has in this study been considered as adults as they most likely produce noise in a similar way. The maximum amount of people in a dwelling was 5, with three children. 22 of the participants answered that other adults usually are at home during the time they work, and 7 answered that children usually are at home during the day.

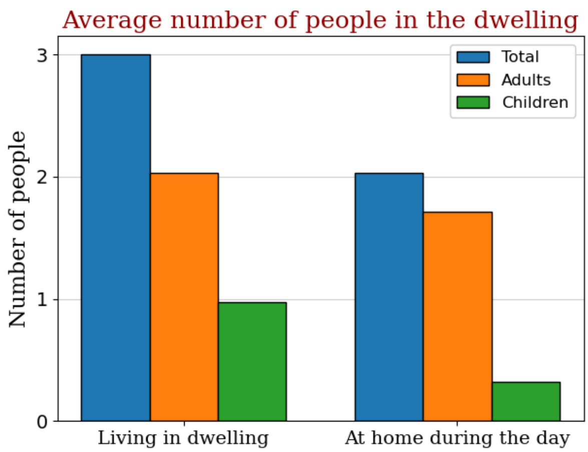

Figure 16. Average number of Adults and children both living in the participants' dwellings and how many use to be at home during the day

6.2.3 Noise-related questions

Table 7 shows the overall annoyance level from noise at home and at the office while working. The mean value is a bit higher at the office than at home, but both categories with high values for standard deviation. There was a wide spread in answers, with the office having a few more participants giving a value of 5 or higher for the disturbance. Out of the participants rating either place as a 5 or more on the annoyance scale, only one participant rated both places as disturbance of 5 or more.

Table 7. Overall annoyance from noise when working.

Annoyance level	**Mean value**	**Standard deviation**	**% of participants answering 5 or more**
At home	2,7	2,2	17
At the office	3,4	2,2	29

Results from both questions 29 and 32 can be seen in Figure 17. The graph shows mean values for disturbance of all sources along with the overall levels for noise disturbance at home and at the office. The black lines indicate 95% Confidence intervals.

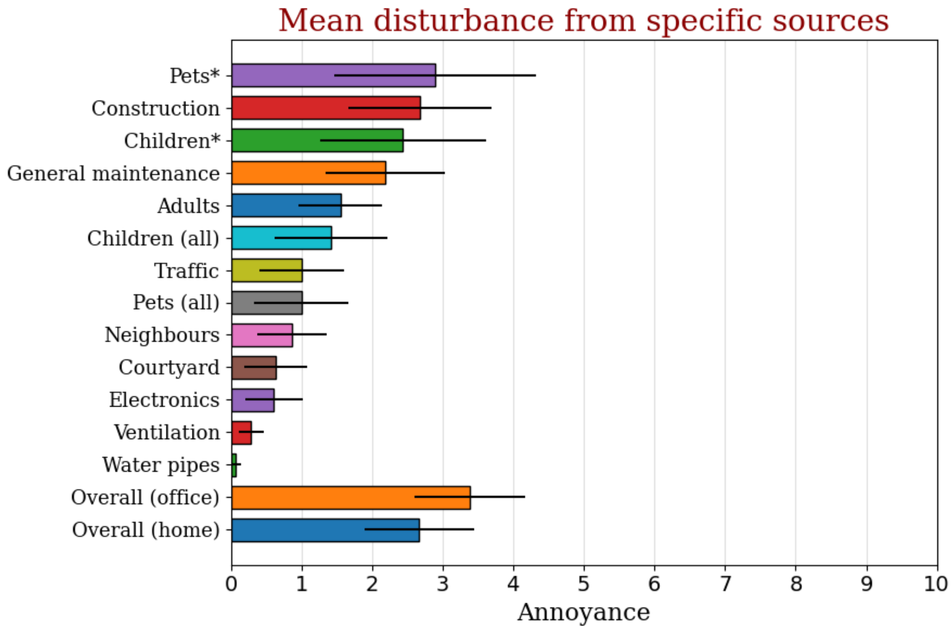

*Figure 17. Mean values for both overall noise disturbance and noise disturbance from specific sources. * indicates smaller samples, removing those who do not have pets/children from the group.*

Table 8 shows the values of average disturbance from specific noise sources along with the standard deviation and the share of participants answering 5 or higher. Some of these sources also have values for a specific selection, described in the comments below the table.

Table 8. Response for annoyance level of different sound sources

Annoyance level from sources	**Mean value**	**Standard deviation**	**% of participants answering 5 or more**
Traffic	1,0	1,7	10
Maintenance work	2,2	2,4	19
Pets	1,0 (2,9*)	1,9 (2,2*)	10 (22*)
Neighbours	0,9	1,4	3
Construction work	2,7	2,9	26
Courtyard noise	0,6	1,3	3
Ventilation	0,3	0,5	0
Water pipes	0,1	0,2	0
Children in house	1,4 (2,5**)	2,4 (2,5**)	13 (22**)
Adults in house	1,5 (1.7***)	1,7 (1,7***)	6 (7***)
Electronics	0,6	1,2	3

**After removing values for participants who do not have any pets, n=9. **After removing values for those who do not have children n=18. ***After removing values for those who do not have any other adults living in the dwelling, n=28. n describes the number of answers in selection groups.*

The biggest source of annoyance when looking at all answers was construction work, followed by maintenance work. Those were also the sources that most people rated as an annoyance of 5 or higher. When looking at special selection groups, pets got the highest mean value when just using values for pet owners, and children in the house being the source that had the second highest rate of scores of 5 or higher when removing values for those who do not have children. HVAC had very low scores in general with water pipes, ventilation and electronics having the lowest mean values of all sources. Furthermore, maintenance work and construction work were also the sources that was rated as 0 the fewest times, with 21 out of the 31 participants giving a value of 1 or higher for both sources.

For the question regarding if there were any disturbing sound sources that were not presented as options, three answers were written by the participants. These did however not have any values of annoyance. Two of them could be considered the same category as construction work, and the third could be considered as courtyard noise.

Figure 18 presents the results from question 30, regarding how often disturbing noises occur. The results are fairly similar between home and office environment. A few more responded that they were not at all experiencing disturbing noises at home, but an equal amount answered that they were fairly or more often disturbed at home or at the office. The majority stated that disturbing noise did not occur often.

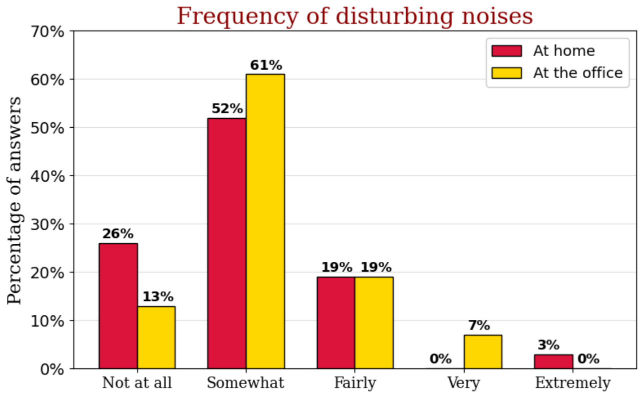

Figure 18. Results from question 30, on how often disturbing noises occur while the participants are working.

The final productivity question regarded how much the participants felt that they lost concentration due to noise, and is presented in Figure 19. For this question there seem to be a clearer difference between the two locations, with more of the answers claiming to be more disturbed at the office. 12 participants stated that they did not lose concentration at all due to noise while working from home, while 5 participants claimed the same thing when working at the office.

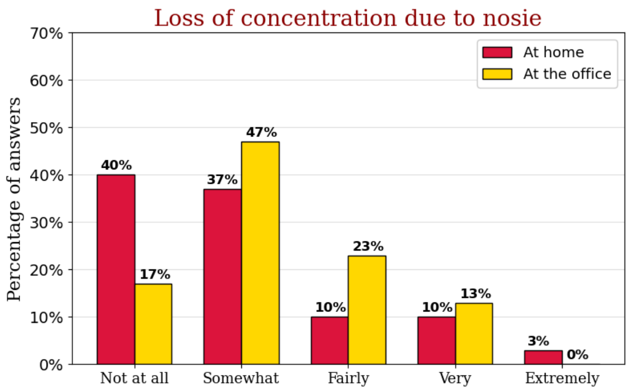

Figure 19. Results from questions 31 about how much the participants feel they lose concentration due to noise while working.

Answers for question 34 regarding usage of playing music, masking noise and hearing protection to shut out noise are presented in Figure 20. A majority of the participants listened to music in at least one of their working environments. 6 participants played masking noise in at least one location. A third of the participants stated that they used hearing protection, however, none of them used hearing protection on both locations. When looking at those playing music or using hearing protection exclusively at either home or the office, the office environment saw more usage of tools to help reduce the effect of noise. 6 participants responded that they did not use either of the tools in the question to reduce the effect of noise.

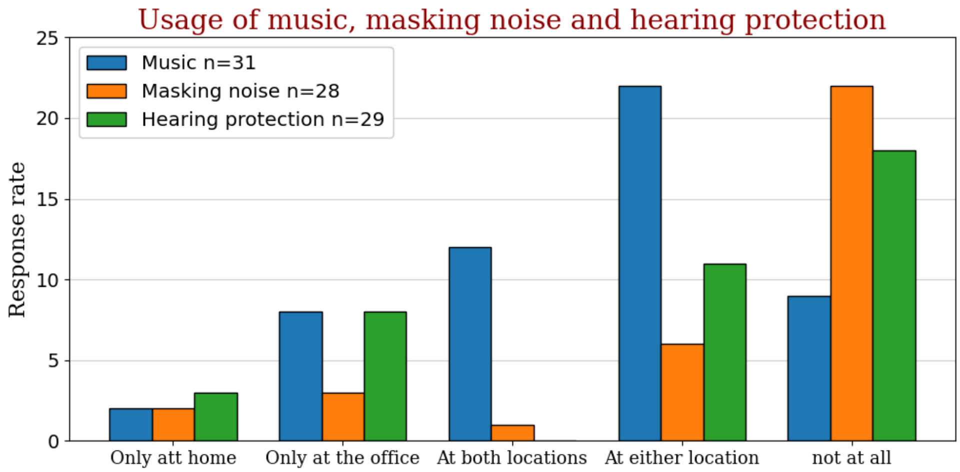

Figure 20. Usage of music, masking noise and hearing protection at home and at the office. n is the number of responses for each question.

6.2.4 Personal questions

Figure 21 shows the age- and gender distribution of the participants along with how they perceived their own sensitivity to sound. Most participants were between 30-45 years old, with just 3 participants being older than 55. 18 males and 13 females participated in the study. Most participants said that they were somewhat sensitive to sound, with a total of 13 participants answering that they were more than somewhat sensitive.

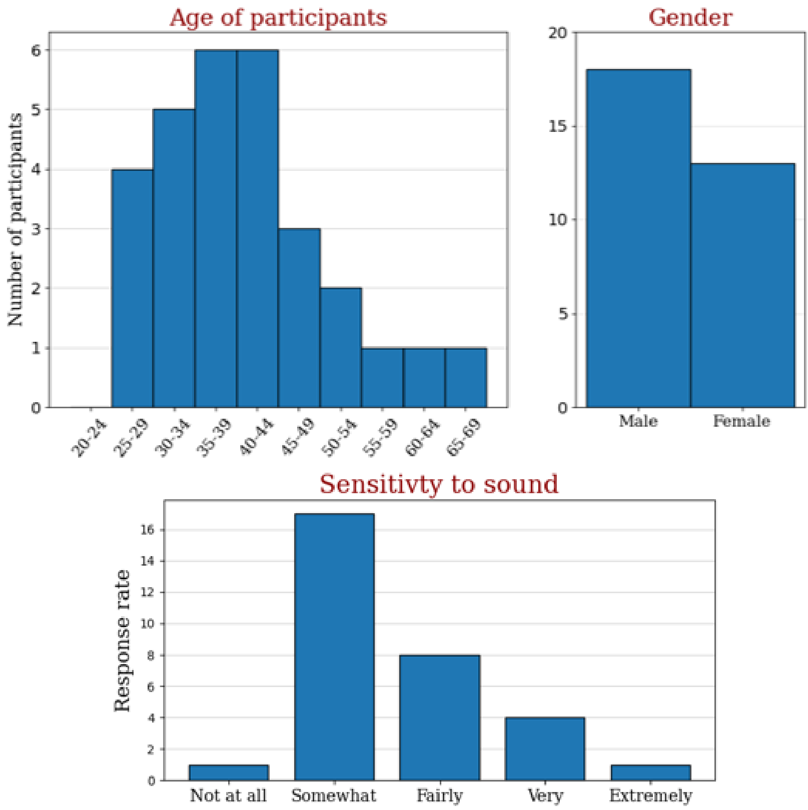

Figure 21. Age- and gender distribution and sound sensitivity of participants

Figure 22 shows how long the participants had been working with their current occupation and for how long they had been employed at Sweco. Most of the participants had worked at Sweco for less than 9 years, with most the largest group being employed for between 3-5 years. Years in occupation was spread a bit more evenly, also including a peak at 3-5 years. None of the respondents stated that they had changed their occupation during the time they had been employed.

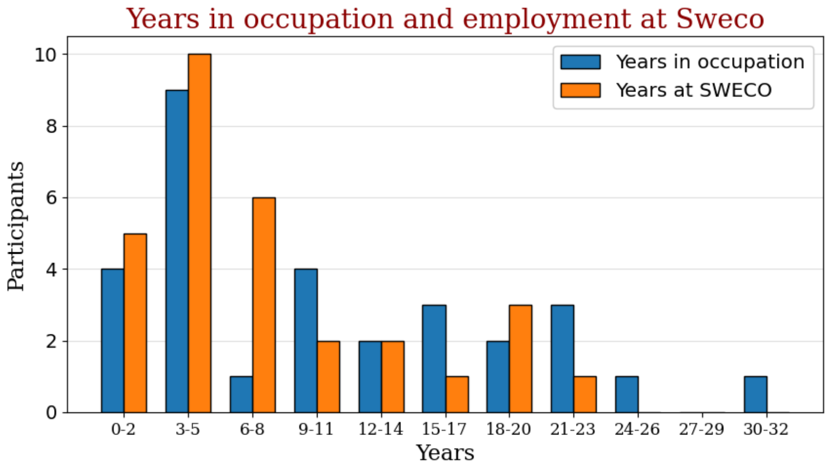

Figure 22. Answers for questions 37 and 38 regarding years in both occupation and years at Sweco.

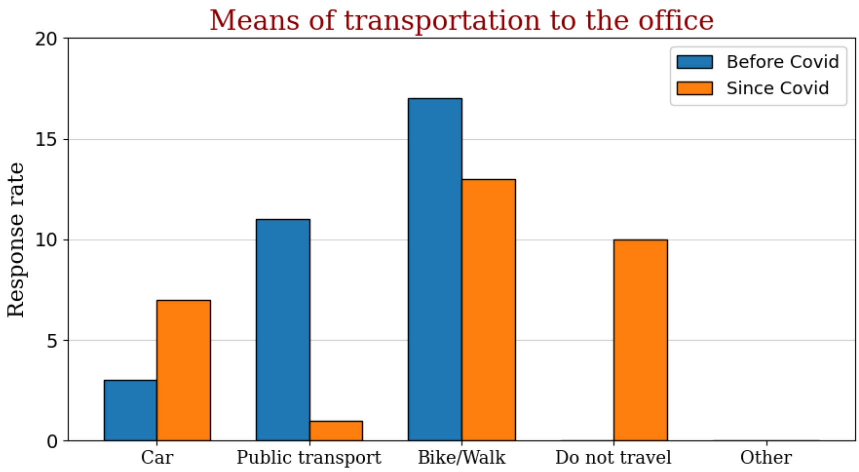

Figure 23. Means of transportation to the office before and after Covid.

Figure 23 shows the responses to questions 39 and 40. Almost all respondents who used to travel to the office by public transportation has either changed their means of transportation or stopped going to the office. The number of participants travelling by car has increased post Covid.

For question 42, none of the respondents was using any hearing aid.

When looking at the question on how the participants wanted to continue working from home after the restrictions were lifted, the result can be seen in Figure 24. 7 answered that they would like to go back as things were before. 10 answered that they wanted to continue working as they were doing when the questionnaire was handed out, and 14 answered that either way was okay. The appeared to be no connection between if the participants wanted to continue distance working as they do now and if they still travelled to the office or not.

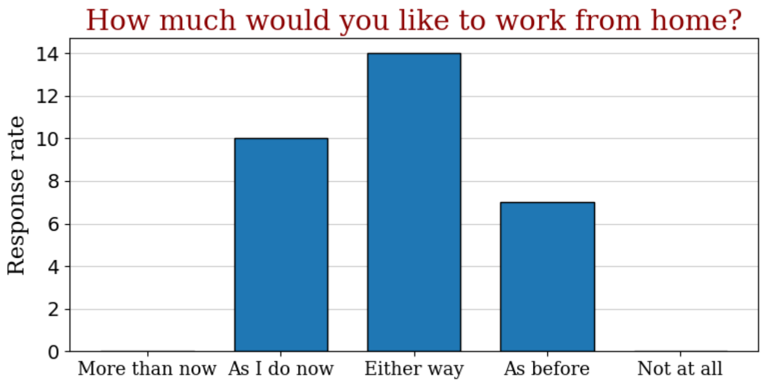

Figure 24. Response rates for how participants wanted to continue with distance working.

6.3 Correlation analysis

6.3.1 Difference between groups based on questionnaire answers

Since the t-test and Mann-Whitney U-test only were analysed with groups including 10 or more participants, some questions were discarded from the test. Table 9 shows the different groupings for each analysed question. Same groupings were used for both t-, and U-test. Some of these questions were just grouped based two answers, such as questions with only two options. Questions 7 and 8 were used together, since there were so many alternatives to answer. It was investigated if those who wanted to work a different type of spot at the office were differentiating from those who were pleased with how they usually worked at the office. To be able to analyse the data of how dwelling type impacted the acoustic perception, terraced buildings and detached houses were considered to be similar enough to be grouped and compared with apartment buildings.

For Question 19, all ordinary rooms in a dwelling were compared to rooms designed as home offices. A few answers were not included in any of the two groups as they were either too different or lacked information for proper classification. Question 39 was divided into groups between those who still travel to the office and those who do not. Without collecting all means of transportation into one group, those who travelled by car or public transportation would not be analysed. In question 40 grouping was instead made between public transportation and other means of transportation, as it was considered that someone might have a different attitude towards travelling if they usually travel in a way that has not been notably affected by the restrictions.

Table 9. Descriptions of the groupings made for analysis using t-test and Mann-Whitney U-test. Sample size for each group is labelled n.

Groupings	***Description***
Q7+Q8	Those who responded they usually work in the place they prefer at the office *(n=13)* compared with those who did not *(n=18)*
Q11	Those who have changed working hours due to noise at home *(n=10)* compared to those who have not *(n=21)*
Q15	Participants living in apartment building *(n=19)* compared to other dwelling types *(n=12)*
Q16	People working on ground floor *(n=11)* compared to a middle floor *(n=13)*
Q19	Participants working from a home office *(n=12)* compared to those working from either bedroom, kitchen, living room or similar answer *(n=16)*
Q22	Those working with the door shut *(n=11)* compared to those working with open door *(n=20)*
Q26	Those who have children *(n=18)* compared to those who have not *(n=10)*
Q34c	Those who work using hearing protection either at the office or at home *(n=11)* compared to those who do not use it *(n=18)*
Q36	Male *(n=18)* or female *(n=13)*
Q39	Those who still travel to the office nowadays *(n=21)* compared to those who do not travel to the office *(n=10)*
Q40	Those who travelled by either car, bike or walking *(n=20)* compared to those who travel by public transportation *(n=11)*
Q41	Those who responded they were not at all or somewhat sensitive to sound (n=18) compared to those who were fairly - or more than fairly - sensitive to sound (n=13)

Table 10. Table presenting p-values from t-tests. First column presents questions used to divide participants into groups. First row contains investigated values. p<0,05 are marked as green. QXa indicated the number and sub-number of a questionnaire question.

p-values using t-test. Only groups > 9 participants

	Q29a	***Q29b***	***Q32b***	***Q32e***	***Q32j***	$L_{A,eq}$	L_{A90}
Q7+Q8	**0,01**	0,55	0,59	0,46	**0,02**	0,17	0,75
Q11	0,09	0,33	0,99	0,36	0,49	0,75	**0,03**
Q15	**0,04**	0,44	**0,04**	**0,02**	0,41	0,98	0,11
Q16	0,88	0,41	0,97	0,34	0,33	0,88	0,50
Q19	0,63	0,12	0,49	0,05	0,43	0,47	0,88
Q22	0,12	**0,02**	0,64	0,15	0,26	0,48	0,50
Q26	0,89	0,17	**0,02**	0,20	0,63	0,48	0,47
Q34c	0,09	0,33	0,64	0,50	0,43	0,33	0,79
Q36	0,78	0,88	0,25	0,13	0,36	0,65	0,54
Q39	**0,05**	0,54	0,43	**0,04**	0,35	1,00	0,89
Q40	0,17	0,13	0,68	**0,02**	0,44	0,25	0,10
Q41	0,76	0,28	0,50	0,53	0,15	0,19	0,81

Table 10 presents p-values from the t-tests used to compare different groups from the questionnaire questions with both questionnaire responses and measured values. Numbers highlighted in green cells are likely to have a correlation. The most impactful sound sources used from question 32 are used for comparison (with exception of noise annoyance from children, since children is instead used as a category). A few of the groupings showed no notable correlation with any of the compared values. Those who wanted to change place in the office *(Q7+Q8)* showed a high correlation with disturbance at home *(Q29a)* but no correlation at all when looking at the same question for the office *(Q29b)*. When looking at those who had changed their working hours at home due to noise *(Q11)* a significant correlation was found with the measured L_{A90}-levels. The ones who had changed hours due to noise had higher L_{A90}-levels.

The grouping of dwelling types *(Q15)* was the only one with more than two comparisons giving a high likelihood of correlation. Those who lived in apartments were more disturbed by noise at home in general *(Q29a)*, noise from maintenance work *(Q32b)* and noise from construction work *(Q32e)*. The question about participants still travelled to the office *(Q39)* gave high correlation in two tests: The ones who still travelled to the office were both more disturbed at home *(Q29a)* and more disturbed by construction work *(Q32e)*. Floor type *(Q16)*, room type *(Q19)*, use of hearing protection *(Q34c)* and gender *(Q36)* showed no statistical difference in any of the tests.

Table 11. p-values using Mann-Whitney U-test with aforementioned groupings. p<0,05 marked green. Continued in Table 12.

p-values using U-test. Only groups > 9 participants

	Q4	***Q5***	***Q6***	***Q9a***	***Q9b***	***Q10***
Q7+Q8	0,74	0,87	0,71	0,47	0,52	0,28
Q11	0,77	0,80	0,95	0,67	0,39	0,25
Q15	0,40	0,59	0,74	0,75	0,73	0,36
Q16	1,00	0,59	0,87	0,36	0,26	0,56
Q19	0,14	0,50	0,96	0,54	0,28	0,27
Q22	0,67	0,12	0,95	0,72	0,16	0,57
Q26	0,94	0,68	0,71	0,37	0,94	**0,02**
Q34c	0,20	0,32	0,25	0,19	0,26	0,86
Q36	0,24	0,68	0,48	0,93	0,32	0,25
Q39	0,28	0,26	0,98	0,54	0,85	0,93
Q40	0,29	0,18	0,14	0,50	0,95	0,87
Q41	0,71	0,34	0,87	0,21	0,70	0,63

Table 12. p-values using Mann-Whitney U-test with aforementioned groupings. p<0,05 marked green.

p-values using U-test. Only groups > 9 participants

	Q30a	***Q30b***	***Q31a***	***Q31b***	***Q43***
Q7+Q8	0,18	0,70	0,06	0,61	0,91
Q11	0,20	0,16	**0,02**	0,59	0,12
Q15	0,07	0,82	0,96	0,54	0,91
Q16	0,87	0,61	0,21	0,58	0,62
Q19	0,52	0,12	0,56	0,07	0,60
Q22	0,46	0,13	0,37	0,07	0,97
Q26	0,69	0,08	0,07	0,15	0,70
Q34c	0,20	0,19	0,94	0,52	0,12
Q36	0,23	0,46	0,41	0,07	0,91
Q39	0,37	0,38	0,71	0,87	0,60
Q40	0,72	**0,02**	**0,01**	0,36	0,13
Q41	0,86	0,19	**0,04**	**0,03**	0,11

Table 11 and Table 12 shows p-values for null-hypothesis tests using the Mann-Whitney U-test. Here, only four of the groupings showed a statistical significance in the tests. Those who did not have any children *(Q26)* living in the dwelling showed a significant increase in how much they changed their working hours and routines *(Q10)*. The grouping for those who had changed work hours at home due to noise *(Q11)* saw correlation with how often they felt lost concentration at home *(Q31a)*, with the ones who had rescheduled their work losing concentration more often. Another grouping showing statistical significance in the U-tests was between those who used to travel by public transportation and those who used to walk/bike/travel by car *(Q40).* The tests gave the results that those who took public transportation felt disturbing noises occurred more often at the office *(Q30b)* and that they lost concentration less often at home *(Q31a)*. None of the other investigated connection gave any statistical significance to reject the null hypotheses. Finally, those who stated that they were sensitive to sound *(Q41)* reported more loss of concentration due to noise both at home *(Q31a)* and at the office *(Q31b).*

6.3.2 Correlation analyses using Pearson's- and Spearman's correlation

Two correlation matrices were formed. One using Pearson's correlation for linear values (also with 0-10 option questions), and the other using Spearman's correlation. The full matrices can be found in Appendix D, and this section will highlight the interesting results, since not many of the correlations had both p-values below 0,05 and |r|>0,5.

The question about where the employees preferred to work had a positive correlation of 0,7 with both the question about where they get the most work done and where they feel the working environment is best. Question 29a and 29b (disturbance by noise at home and office) had correlations with Questions 31a and 31b (loss of concentration), respectively. In both cases the correlation was just above 0,5, which indicates that an increase in disturbance by noise will lead to an increase in concentration loss.

There were no significant correlations between specific noise sources and other variables, but there were a few correlations between specific noise sources and other noise sources. Examples of this is that people who were more disturbed by maintenance work were also more disturbed by traffic (r=0,53), construction work (r=0,6) and sound from courtyard (r=0,71).

A second set of correlation analyses was done with the usage of grouping values. Independent variables were grouped, with participant with a similar value being included into that group. The dependant value was calculated as the mean value in that group. Most analyses using this method contained 5 different groups. The intervals used for these groupings are presented in Table 13. The used independent values are written within parentheses, and the values were chosen to get a similar number of participants within each category and try to eliminate specific outliers that might skew the analyses.

Table 13. Grouping intervals for independent variables in grouped correlation analyses. Values used are written within parentheses.

Independent variable	***Grouping intervals***
Q17	Floor number grouped by floor 1 *(1)*, 2 *(2)*, 3-4 *(3,5)* and 5+ *(6)*.
Q18	Dwelling size in square metres grouped by 62 and below *(50)*, 63-87 *(75)*, 88-112 *(100)*, 113-137 *(125)* and 138+ *(150)*.
Q21	Room size in square metres grouped by 7 and below *(5)*, 8-14 *(10)*, 15-24 *(20)*, 25-34 *(30)* and 35+ *(40)*
Q26	Number of children grouped by 0 *(0)*,1 *(1)*, 2 *(2)* and 3+ *(3)*.
Q35	Age of participants grouped by 32 and younger *(30)*, 33-37 *(35)*, 38-42 *(40)*, 43-47 *(45)* and 48+ *(50)*.
Q37	Years in current occupation grouped by those working **at least** 1 year or less *(1)*, 3 *(3)*, 5 *(5)*, 7 *(7)* or 10+ *(10)*.
Q38	Years at Sweco grouped by those working **at least** 1 year or less *(1)*, 3 *(3)*, 5 *(5)*, 7 *(7)* or 10+ *(10)*.
Commute time	Commute time in minutes grouped by 14 and less *(10)*, 15-24 *(20)*, 25-34 *(30)*, and 34+ *(40)*.
$L_{A,eq}$	$L_{A,eq}$ at home in dBA grouped by 42,4 and below *(40)*; 42,5-47,4 *(45)*; 47,5-52,4 *(50)*; 52,5-57,4 *(55)*; and 57,5+ *(60)*
L_{A90}	L_{A90} at home in dBA grouped by 23,7 and below *(22,5)*; 23,8-26,2 *(25)*; 26,3-28,7 *(27,5)*; 28,8-31,2 *(30)*; 31,3-33,7 *(32,5)* and 33,8+ *(35)*.

*Table 14. r-values using Spearman correlation. Observations grouped into mean values. 0,5<|r|<0,7 marked as light green. |r|>0,7 marked as green. * indicates p<0,05.*

r-values using spearman correlation

	Q4	***Q5***	***Q6***	***Q10***	***Q31a***	***Q31b***	***Q41***
Q17	0,40	0,40	0,40	-0,80	-0,40	0,80	0,95
Q18	0,60	-0,40	0,67	-0,30	0,30	-0,45	0,36
Q21	0,20	-0,40	0,40	-0,40	**1,00***	-0,40	-0,40
Q26	-0,40	-0,20	-0,40	-0,40	0,80	-0,20	0,20
Q35	0,50	-0,20	-0,20	-0,46	-0,30	-0,70	-0,70
Q37	**0,89***	0,30	-0,71	-0,46	0,10	0,21	-0,30
Q38	0,20	0,10	-0,31	**-0,90***	-0,21	-0,11	-0,67
Commute time	0,95	0,20	0,40	0,40	-0,60	-0,40	-0,80
$L_{A,eq}$	0,10	-0,20	-0,30	0,15	0,1	0,05	-0,60
L_{A90}	-0,37	0,09	0,03	0,15	0,81	0,09	-0,46

From the correlations shown in Table 14, three comparisons show a high correlation along with a p-value that indicates that the correlation is significant. The groupings based on room size *(Q21)* showed a positive correlation with loss of concentration at home *(Q31a)*. The questions regarding years in both occupation and employment showed significant correlation. Years in occupation *(Q37)* showed a positive correlation with where they felt they get most work done *(Q4)*. A positive correlation in this case means that those working for a longer time in their current occupation tended to consider they were more productive at home than at the office. Years of employment at Sweco *(Q38)* showed a negative correlation with general change in working hours and routine *(Q10)*.

Table 15 gives a continuation of correlations using the same method as presented in Table 14. Here, the correlations with linear values are shown, and the three sound sources with the highest average disturbance are presented along with general noise disturbance at home and at work. Two sets of grouped values showed a significant correlation with other variables using the Pearson correlation. Dwelling size in square metres *(Q18)* showed a negative correlation for overall noise disturbance at home *(Q29a)*, disturbance by maintenance work *(Q32b)* and disturbance by construction work *(Q32e)*. Grouping by age *(Q35)* also showed significant negative correlation with both overall disturbance at home and noise from maintenance work. (The independent variables of dwelling size compared to age did not show any significant correlation).

*Table 15. r-values using Pearson correlation. Observations grouped into mean values. 0,5<|r|<0,7 marked as light green. |r|>0,7 marked as green. * indicates p<0,05.*

r-values using Pearson correlation

	Q29a	***Q29b***	***Q32b***	***Q32e***	***Q32j***
Q17	-0,32	-0,26	-0,92	-0,48	-0,80
Q18	**-0,89***	-0,15	**-0,97***	**-0,98***	-0,75
Q21	0,60	-0,36	-0,46	-0,91	0,13
Q26	0,22	-0,15	-0,70	-0,10	0,88
Q35	**-0,92***	-0,26	**-0,91***	-0,86	-0,84
Q37	-0,22	0,12	-0,73	-0,10	0,03
Q38	-0,83	0,09	-0,67	-0,45	-0,22
Commute time	-0,60	0,26	0,11	-0,79	-0,69
$L_{A,eq}$	-0,47	-0,66	0,13	0,01	-0,13
L_{A90}	0,59	-0,46	-0,04	0,74	0,24

Using the results presented in Table 14 and Table 15, regression analyses were created for the comparisons with high and significant correlation. The generated models whose constants all had p-values < 0,05 were then investigated, and those considered most reasonable to use as prediction models are presented in Figure 25-Figure 28.

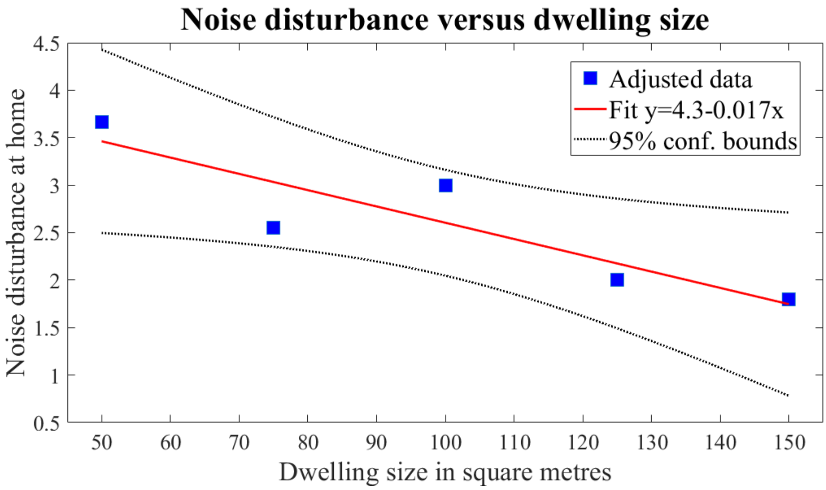

Figure 25. Regression model for noise disturbance at home versus size of the dwelling, $R^2 = 0{,}8$.

Figure 25 shows the linear regression model for noise disturbance at home *(Q29a)* versus dwelling size in square metres *(Q18)*. The blue squares mark the grouped observations based on collected data. The red line shows the linear model, with the equation y = 4,3-0,02x. y in this case indicates values for noise disturbance at home from the survey, and x denotes the dwelling size in square metres. This can be translated as:

$$ND_{Home} = 4{,}3 - 0{,}017A_{Dwelling}$$

Where ND_{Home} is the overall noise disturbance at home and $A_{Dwelling}$ is the dwelling size in m^2. For example, this would mean that that a person living in a dwelling with an area of 135 m^2 would have an average noise disturbance according to the following:

$$ND_{Home}(135) = 4{,}3 - 0{,}017 * 135 = 2$$

The dotted line shows the 95% confidence interval for the line. This shows the uncertainty of the model based on the observations used. A low number of observations will naturally result in a wide confidence interval.

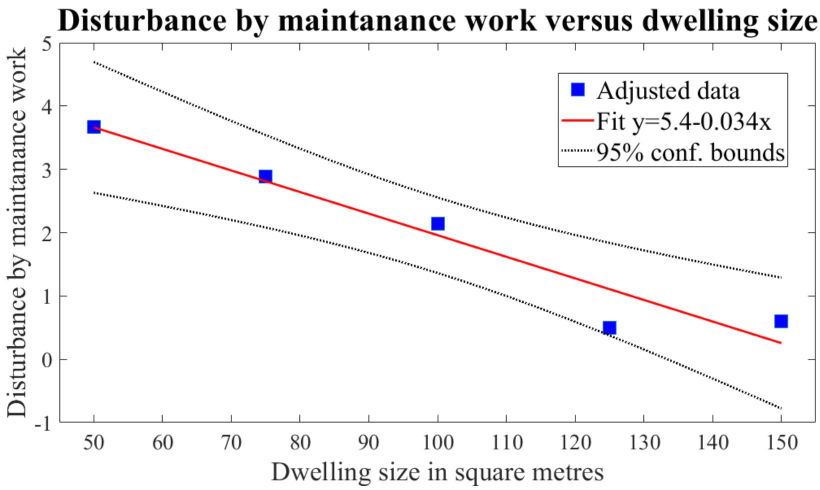

Figure 26. Regression model for noise disturbance from maintenance work versus size of the dwelling, R^2 = 0,93.

Figure 26 shows the disturbance by maintenance work versus dwelling size, and a few examples of the disturbances based on dwelling size from the models are shown in Table 16.

Table 16. Examples of overall noise disturbance at home and noise disturbance by maintenance based on dwelling size using regression model.

$A_{Dwelling}$ [m²]	ND_{Home}	$ND_{Maintenance}$
50	3,5	3,7
70	3,1	3,0
100	2,6	2,0
150	1,8	0,3

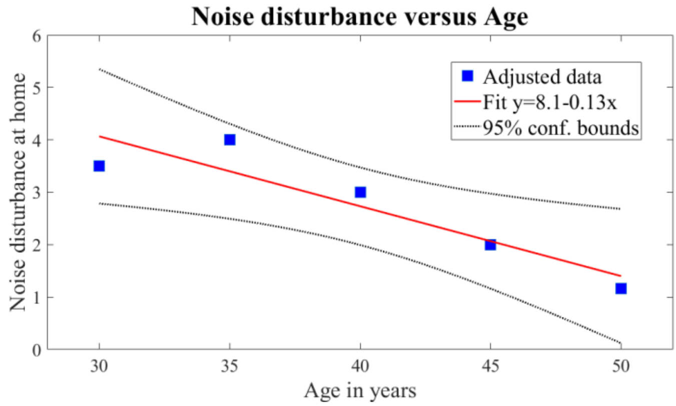

Figure 27. Regression model for noise disturbance at home versus age, R^2 = 0,85.

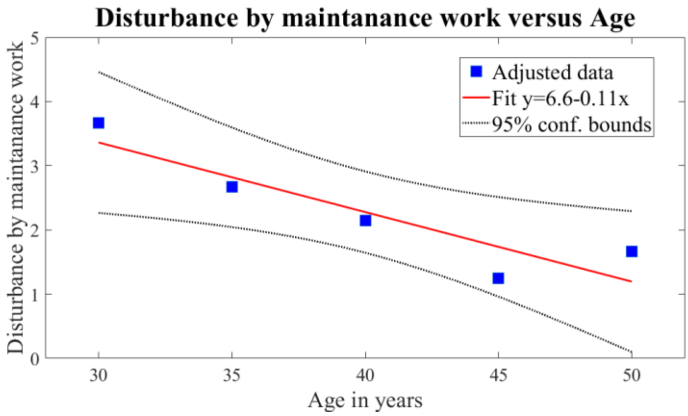

Figure 28. Regression model for noise disturbance from maintenance work versus age, R^2 = 0,83.

Figure 25-Figure 28 shows graphs of the regression models considered both significant and plausible enough from the analysis using grouped values. The formulas for the four models along with their R^2-values are summarized in Table 17. All the presented models have a R^2-value of at least 0,8.

Table 17. Formulas from simple regression models using grouped observations.

Dependent variable	**Model**	R^2
Overall noise disturbance at home	$4,3 - 0,017 * A_{dwelling}$	0,8
	$8,1 - 0,13 * Age$	0,85
Noise disturbance by Maintenance work	$5,4 - 0,034 * A_{dwelling}$	0,93
	$6,6 - 0,11 * Age$	0,83

6.3.3 Multiple linear regression

The final part of the statistical analysis consisted of multiple linear regressions. The dependant variables from the correlation analyses were tested with all possible configurations of predictor variables. This was once again done using all possible observations, and not the grouped values. Only models where $R^2>0,3$ and $p<0,05$ for all constants was inspected. The three following multiple regression models presented in Table 18 were the ones with highest R^2 and intuitively the easiest ones to explain.

Table 18. Multiple linear regression models using all observations.

Dependent variable	**Model**	**R^2**
Preferred workplace (1=office preferred, 5=home preferred)	$3{,}8 - 0{,}75 * Children\ at\ home - 0{,}20 * Maintanance\ work$	0,39
	$3{,}8 - 0{,}66 * Children\ at\ home - 0{,}18 * Construction\ work$	0,40
Overall noise disturbance at home	$1{,}1 + 0{,}29 * Construction\ work + 0{,}54 * noise\ from\ adults$	0,38

As the results in Table 18 shows, the models presented are dependent on the number of Children at home during the day, noise from adults and noise from maintenance and construction work. Number of children at home had a big impact on where the workers preferred to work in the models, meaning that the office was more preferred with an increasing number of children at home during the day. An increasing disturbance by maintenance and construction work also led to the office being the preferred workplace. Noise from adults and construction work where the most impactful factors for overall noise disturbance at home. No significant models using all three parameters were found.

7. Discussion

7.1 Interpreting results

This section will highlight interesting results from the measurements, questionnaire and statistical analyses.

7.1.1 Measurements

When looking at the measured data presented in section 6.1, there is a much bigger difference in SPL between the home measurements than between the office measurements. The participants who had the highest $L_{A,eq}$ all stated that they were in a meeting for most of the time. Still, there is a big difference between the loudest office measurement with 5-6 workers being fairly close to the microphone while talking among themselves and the loudest measurement at home.

The reason that the office measurements, even in the relatively occupied zone, does not come nearer to the loud home measurements could depend on several factors. One factor might be that a person sitting in a meeting at home can use a loudspeaker instead of headphones while listening in. They also do not have to change their behaviour to not disturb others. At the office employees usually develop routines for how they should behave when other co-workers are nearby. Alternatives are trying to keep their voices down when discussing with someone else, using headphones or even leaving the open office space and entering one of the conference rooms when more thorough discussions are needed. This shows a possible change of behaviour that the participants feel freer to make noise while working from home, without needing to adjust depending on nearby co-workers. This is further emphasized by Bradley (2003) who stated that a good acoustic environment in an open office is dependent on the employees to keep the sound levels down.

The other reasons could be related to the room acoustics and dimensions. Home measurements executed in very small rooms means that the measurement device needed to be closer to a direct sound source than at the office measurements, which could give higher measured values. There are also a lot of acoustic adjustments made at the office of Sweco to reduce the amount of noise, such as acoustic ceilings and separating screens between office desks. Much of the improvements investigated in the mentioned study by Keränen, Virjonen & Hongisto (2008) has been done at the office, which will have an impact on the reduction of sound propagating.

Since there were still such high Covid restrictions when the measurements were carried out, the different zones were occupied very unevenly. Three of the measured zones were considered to be somewhat representative of the office environment before Covid. Zone 2 on floor 7 shown in Figure 11 had the highest occupancy rate during the hour of measuring, and could be considered an example of what a day with low to average occupancy would have looked like before Covid. On floor 2, zones 1 and 9 could be considered representative. Zone 1 is a quiet zone, and even though there were not many people working there during the measurement, the sound levels would likely not increase that much with a higher occupancy. Zone 9 is a meeting room, and the acoustical conditions there are probably quite similar to the home offices.

When looking at levels of L_{A90}, the office had little differences between the different measurements. This is logical, since L_{A90} to a large extent is the same thing as background noise. In the office, the background noise does not change significantly depending on where you are, due to much of the nose coming from installations. Installation noise is probably almost identical at most positions in the office, and extra noise might come from computers or sound sources from the outside. At home the L_{A90}-levels will obviously vary a lot more depending on installations at home, and also the fact that outside noise will vary depending on building location and sound isolation.

7.1.2 Questionnaire

Some of the questions in the questionnaire did not provide any useful information due to the response rates, with some questions almost exclusively being answered with one option and therefore not useful in any comparisons.

The Questions regarding where the participants preferred to work, felt more productive, evaluated the working environment and how they wanted to continue with distance working all saw similar answers. The mean values were very close to the neutral option with almost as many being positive to the office as being positive to the at home environment. An interesting point to note is that almost a third of the asked participants wanted to continue working from home as much as they did when the study was made. The question to see how the employees wanted to work at the office showed that many wanted to change work position, but that a majority still rather wanted to be in an open plan office than cell office or quiet zone. Fixed seats tended to be what was regarded highest. At home almost half of the participants worked in a room used as a home office. Since only 6 of them responded that they had had home offices at home before Covid, this shows that distance working has required employees to redesign their home environment to improve the preconditions for a satisfying working place.

For the questions regarding disturbance by noise in general and by specific sources, the answers showed a bit more general disturbance by noise at the office, although the standard deviations were high for the answers. What the selection shows is that there are more people that seem to be really bothered by noise in general at the office compared to the home environment. For the specific noise sources, maintenance, construction, children and other adults were the most disturbing noise sources. Pets were also considered one of the most disturbing sources when only looking at those who has pets, however, there were not many participants who had pets in the study. A fourth of the participants were really disturbed by construction work, and a fifth were really disturbed by maintenance work. Maintenance work could be considered a more generally disturbing source than construction work because of its recurrence. The majority of those annoyed by construction work where living in a building where there were extensive renovations being carried out, or lived close to a building site. It is safe to assume that the answers for noise by construction work would look differently for many participants in the near future, whereas the maintenance would cause a similar noise. Sound from adults and children would go hand in hand with the fact that talk from co-workers tended to be the most annoying noise source in the office (Haapakangas et al. 2008). Installations and electronics were barely considered disturbing at all, and very few of the participants were disturbed by noise neighbours even though the majority lived in apartment buildings.

When looking at the questions more directly related to productivity, a few of the responses showed more disturbance when being in a meeting while working from home. Commonness of disturbing noise was fairly equal for both home and office environment. When asked about of loss of concentration due to noise the answers show that the asked participants in general felt they lost more concentration at the office. This can be compared to the study by Haapakangas et al. (2008) that concluded that workers in open offices were more disturbed in general and that the workers themselves estimated a daily time-waste of 20 minutes due to lost concentration caused by noise. Causes of a higher loss of concentration and productivity can, as mentioned in previous studies, come from an increase in background noise (Jahncke, 2012) or the perceived annoyance of specific sounds in the environment (Errett et al, 2006). The reason behind meetings being preferred at the office is most likely that there are secluded meeting rooms that can be used when needed. There are also disturbing effects apart from noise that can be disturbing in a meeting, such as visual disturbances or family members interrupting.

7.1.3 Statistical analyses

There were almost no good or high correlation when looking at single parameters, either measured or from the questionnaire, compared to dependent variables. This is likely due to the small number of participants which causes statistical uncertainty in the analyses. Outliers are affecting the statistical results much more when looking at a small data set. One must, however, also take into consideration that the dependent variables are based on what people feel and perceive. It is therefore logical that while single parameters are more impactful than others, there are lot of things to take into consideration when asking about where they prefer to work and how much they are disturbed. This can be connected to the research made by Sundstrom (1994) that concluded that office workers in general are disturbed by one or two noise sources, but that the specific noise sources that are perceived disturbing vary a lot between the workers. Noises that feel very disturbing by some are barely noticed by others. This is even more accentuated in a research looking at the home environments. When looking at the office, all employees will have similar preconditions if they are sitting in the same office. At home there are many more parameters that comes into the equation. Location of the building will change the noise from external sources. Building type and materials in the building will change how much noise that can be heard from both neighbours and sources outside the building. Children, adults and pets at home will also make a big difference in the noise generated from inside the building. Based on this, the statistical analysis is more likely to find the parameters that in general are more impactful than others, even if the magnitude of the impact is hard to determine.

When looking at the t- and U-tests, several correlations could be found. On the other hand, some of the correlations are more than likely accidental results due to the limited sample size. For example, it seems implausible that employees who wants to change place of work at the office would be directly correlated to a noise annoyance at home when looking at a larger selection. A similar observation is that those who had children had a significant increase in disturbance by maintenance work compared to those who do not have children, which is improbable to have a real correlation. Despite this, the analyses saw some correlations that may well be of actual significance. The result that those living in apartments are more disturbed by noise in general at home along with a higher disturbance from maintenance work and construction work may well be true. Apartment building are often exposed to more noises since there usually are people living both underneath and above the dwelling. Out of the participants in this study, the ones living in apartment buildings were in general living more centrally, while the ones in detached and terraced houses were often living in the outskirts of their town. This is likely a reason for the ones in apartment building to be more exposed to construction work and maintenance work.

The ones who reported that they had changed their working hours due to noise at home had higher measured L_{A90}-levels along with a higher loss of concentration when working from home. Those who still travelled to the office were in general more disturbed by noise at home, as well as a significant change in disturbance by construction work. This also makes sense, since the ones who are most disturbed by noise could feel a higher need to go somewhere else to do their work or work at a time when noise levels are less disturbing.

The ones with children responded with a smaller change in working hours and routine than those who had none. This is an interesting result, since the multiple regression analysis regarded the number of children at home as one of the most impactful variables on where they preferred to work. The reason could be that if there are children still going to school or day care, the parents are not able to change their routines too much, and tries to get their work done during the time the children are away from home. The final probable correlation found in the grouping comparisons were that the ones who considered themselves sensitive to sound lost concentration more easily at both home and at the office. It has been shown in multiple studies that sound sensitivity is directly connected to concentration.

For the correlation analyses using all values, there was only a few high correlations. Preferred workplace had a high correlation with were the workers felt they were more productive. There were also high correlations between disturbance by noise and loss of concentration. This seem to indicate that the responding workers want to work at the place where they feel their productivity is best, and that the overall noise annoyance is a large factor to loss of productivity.

Using the linear regression models, dwelling size, age of the participant, children at home along with noise from maintenance and construction work were the most impactful variables when looking at noise disturbance and preferred workplace. The linear regression using grouped observations are of course not as reliable as a model using all observations, but gave high correlation coefficients along with low p-values. Dwelling size is, not surprisingly, impacting the noise disturbance at home, as those with large dwellings usually have more options on where to work. Larger dwellings make it easier to work in a secluded area if there are other persons at home. The smallest dwellings in the study are apartment buildings, and as the t-tests showed, those in apartments were generally more disturbed by noise.

Age could depend on the hearing deteriorating the older you get, and the older participants therefore not being so annoyed by noise as the younger. Arguments could be made that it also affects that the oldest of the participants no longer have children living at home, but the models are quite consistent even in the range of 30-45 years of age. The effect of age on noise annoyance was investigated in a study by van Gerwen et. Al (2009). The study was made specifically on traffic noise and noise from aircrafts, but included data from 60 000 individuals in the ages 15-102. The study found that people tended to be annoyed the easiest around 44 years of age, with both younger and older people being less annoyed in general. The regression model based on the Sweco employees also showed a decline for the older ones, but showed an increase in disturbance by the younger respondents, which would contradict the study by Gerwen et al. The reason the regression models shows that the younger people (aged 35 and younger) are more disturbed could have more reason than just reaction to noise. An example of this could be that all participants aged younger than 35 were living in apartment buildings, which the t-test showed had more disturbed residents in general.

7.2 Limitations in result and method

The measurement process had to be very simplified due to covid restrictions. The focus had to be on how much sound that is produced from a worker and his/her surrounding, and then compared to the office noise levels. Ideally, measurements would also have been made at the participants home offices when they were not working in order to see how the sound that is not produced from the participants themselves varies. The problem would be to try and find a representative value, as many stated in the questionnaire that they were as most annoyed by sound that often do not occur a major part of the working day (maintenance work or children arriving home from school for example). A more representative measurement might have been made by doing a measurement for an entire day. This could be done like the process by S.H. Park et al (2017) where noise from neighbours was investigated by monitoring SPL for 24 hours. For a project only regarding acoustics while working, the 24 hours could be reduced to the time the employees normally work. This would however require permission to do recordings during the time to be able to determine the source of different sounds to see if they match noise sources stated in the questionnaire answers. It would also require the employees themselves to not produce any sounds, which ideally would mean that the measurement would be conducted during a day that they are working at the office. When the project was being executed, many of the participants stated that they were not going to the office at all, which would remove this possibility. Finally, both increased amount of data and adding records would take work and time which would not be possible to do within the time frame of the project.

The initial plan for doing the office measurement included hopes that the amount of COVID cases would decline much more than it actually did. Most of the employees who took part of the project were working on the environment division on the second floor. As different floors are occupied by different divisions withing Sweco it is not fully comparable on how they work and how much sound that is produced during the day. The second floor has seen a high number of people working from home during the duration of the pandemic, and sound levels would be lower than it was before, which probably would be what most of the participants would think of when answering the questionnaire. Since there was no possibility to wait for the restrictions to ease off and people going back to working at home, an approximation of how the sound levels were before had to be made. There were still a few floors with more people working from the office, so measurements were made there to try representing the sound levels on floor two.

Questions 2 and 3 in the questionnaire regarding how much of the employee's time that they spent working at home before and after COVID-19 was not used in the analysis. This was due to the answers being too similar. A more thorough analysis could have been made if a larger part of the selection were working more from home before COVID-19 as well. Nearly all the participants were working almost all their time from home when the measurements were made compared to 0-20% before COVID-19. This does, however, help to illustrate how big of a change the pandemic has made on the working situation.

A few additions to the questionnaire responses were told by the participants either verbally or via e-mail that the participants felt would be interesting to look at. Some of these inputs came after the questionnaire was sent out and could not be included in the questionnaire, while others were told when doing the measurements and could be thought about. One of the inputs gathered before the questionnaire was finalized regarded whether employees had trouble with their environment being too silent. This was disregarded from the study as it was considered a problem more towards behavioural science than an acoustic problem. It is also most of the times a problem easier to solve for the employees themselves than problems regarding too much noise.

Another opinion that was presented after the questionnaire was sent out was about how noise affects work in other ways than loss of concentration. The participant specifically gave examples of noise that makes it harder to have meetings at home, and outside noise that makes it troublesome to work with open windows during times of warmer climate. In a further study it could be interesting to look at more questions on how noise in particular affects different aspects of an employee's work.

7.3 Further studies

For further studies, more participants should be recruited to do measurements, both while working and without the sound produced by the participant themselves. With more participants comparisons between for example dwelling types, age groups and how much they worked at home in the past will be easier to make with a larger selection. It would also have been interesting to be able to compare perceptions of groups who worked differently before Covid restrictions. Further studies should aim to involve participants working from a more traditional cell office environment, but also workers who are more used to working from home. When looking at groups with more experiencing of home office work, more questions could be asked – to them specifically – on what measures has been made to improve working environment at home.

A later addition to the research could also measure the acoustical parameters of the room, something that was considered cumbersome to ask the participants to do themselves, without much knowledge on sound measurements. Acoustic parameters related to psychoacoustics would also be relevant to investigate, since sound pressure level did not seem to have a significant relevance.

It would also be interesting to see how participants would change their attitude after the pandemic has passed. A second questionnaire could be designed to investigate which place that most people prefer to work when it is easier to travel to the office again.

7.4 Thoughts on the future

This final discussion chapter is a more speculative section on the future based on the results of the questionnaire, other studies and discussions with both supervisors and office workers.

When this report was written, many workers had spent most of their time at home for the past year. This is a lot of time to get settled to a different style of working and, as the questionnaire results shows, has resulted in a lot of changes in working hours, routines and even physical changes of the rooms at home. A third of the asked workers stated that they wanted to continue working from home to the same extent as they were currently doing. When including the ones that stated that either way was okay, the future will most likely see a lot of workers continue to work from home to a great extent even when all restrictions are gone.

With the assumption that distance working is not just a temporary action, this will lead to changes in how the office is being used. When restrictions are eased and the risk of infection has waned, the office might be used mainly for the kind of work that requires direct interaction between co-workers. Individual work could very well continue as it has done for the past year, with the ones feeling they need to work at the office doing so. Discussions about projects, group meetings and brainstorming are more likely to take place at the office in groups. Group days are being discussed in workplaces, where certain days of the week are appointed as office days, and the rest of the days are up to the worker to decide where to work. Having the office as a place of discussion, meetings and ideas – both for social and work-related reasons – could alter the stance an individual has on where to work. The questionnaire showed that those more disturbed by noise at home where still travelling to the office, but if other groups are discussing at the office spaces, the home office might be preferred again for individual work. The number of other family members at home during the day might also decrease when the restrictions are eased.

Delving further into the thought that distance working is becoming more of a permanent solution for many companies, the questions about working environment will become more relevant. As it is the employer's responsibility to ensure a good working environment – when working from home as well (Arbetsmiljöverket, 2021) – guidelines will need clarifications in the future. Even the acoustic environment at home is stated as the employer's responsibility by the Swedish work environment authority. There are no clear instructions on how to implement such a responsibility, and of course an employer can not affect noise from construction work or something similar but could instead focus on noise reducing arrangements or custom-made earplugs for those who need it to concentrate. The employer's responsibility will also be discussed in a lot of areas that are not related to acoustics, such as funding of office equipment for home offices.

There is also the problem of how to use office buildings. As more people chooses to work from home, a large portion of the office will be unoccupied most of the time. With smart scheduling of different groups having group meetings on different days, lot of companies will be able to reduce the expenses by working from smaller buildings or renting out parts of the building to other companies. The hard balance in this comes when looking at the questionnaire responses where the majority wanted their own specific work desk, either in a cell office or a fixed seat. A reduced number of workspaces would require activity-based workstations and flexible workspace to be dominating to work.

8. Conclusions

The purpose of this study is to examine how office workers feel about distance working, with a focus on the impact of sound environment. This chapter attempts to answer the research questions based on the results.

The largest selection of responses belonged to the neutral options when it came to preferred workplace and how they wanted to work from home in the future. Still, almost a third of the asked participants wanted to continue working from home in the same extent as they did when the study was conducted. Those who still travelled to the office responded they were more disturbed by noise at home, hinting there could be a direct connection between noise disturbance and preferred workplace.

The measured equivalent sound levels where in general higher at the homes of the participants than at the office, but clear connections between opinions and sound levels were not found. This indicates a more thoughtful behaviour when it comes to produce noise at the office, and more freedom when working from home. The acoustical arrangements at the office also have its part in the reduction of sound.

Productivity is a hard parameter to measure. When asked about where the participants get the most work done, the answers where divided close to even between the office and at home. A few more felt disturbed while in a meeting when working from home, while concentration loss due to noise was higher at the office.

For the general sound environment, the average answers showed a bit more noise annoyance in the office than at home, but not a big difference. The questionnaire showed that more people chose to play music or use hearing protection to reduce the impact of noise while being at the office. The most impactful noise sources when being at home was construction work, maintenance work and noise from children and adults within the dwelling. Those living in apartment building were in general more disturbed by construction, maintenance and overall noise levels.

The analyses of data showed that single parameters are hard to use as predictors when examining such a broad question as preferred workplace or perceived annoyance. The factors that showed biggest decrease on sound annoyance was larger dwellings and less disturbance from construction work and maintenance. Much noise from maintenance and construction works along with having children at home during the day were the parameters that led to a worker preferring to work from the office instead of teleworking.

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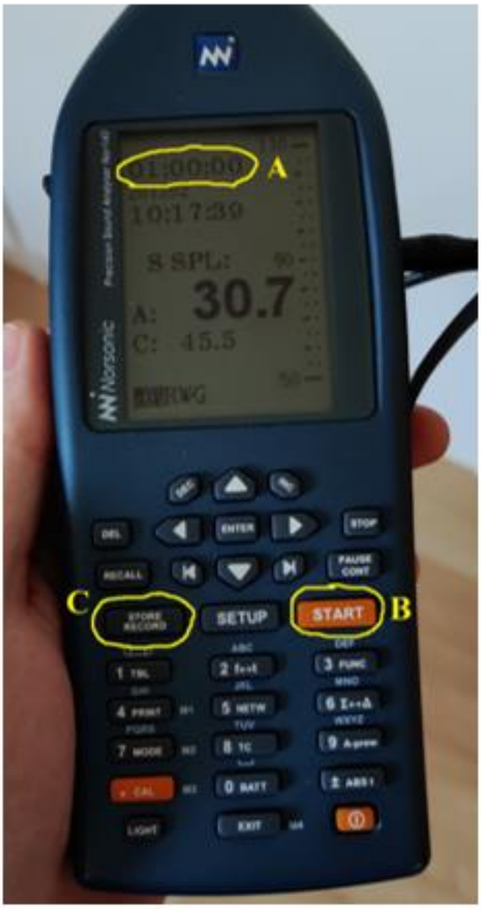
Appendix

Instruktioner för mätning:

1. Placera mätapparaten ett par meter ifrån där du sitter och arbetar. Mätapparaten ska inte stå precis intill en vägg eller hård yta.

2. Koppla in strömsladden i luckan på mätapparatens högra sida.

3. Mätapparaten kommer starta upp och se ut såhär när den laddat klart:



4. Mätningen:

A: Visar hur lång tid mätningen är inställd på, detta ska inte behöva ändras.

B: För att starta mätningen är det bara att trycka på START-knappen. Mätningen kommer därefter avslutas automatiskt när den kommit upp till angiven mättid.

C: **OBS**! För att mätresultatet ska sparas måste man trycka store record efter att mätningen avslutats. Om mätapparaten stängs av innan detta går all data förlorad. När datan har sparats kommer det stå dagens datum högst upp på skärmen, följt av ett filnummer som slutar på bokstaven S.

Efter detta kan ni dra ut strömsladden och stänga av apparaten på knappen nere till höger så är mätningen klar.

Skulle något problem uppstå är det bara att ringa mig på:

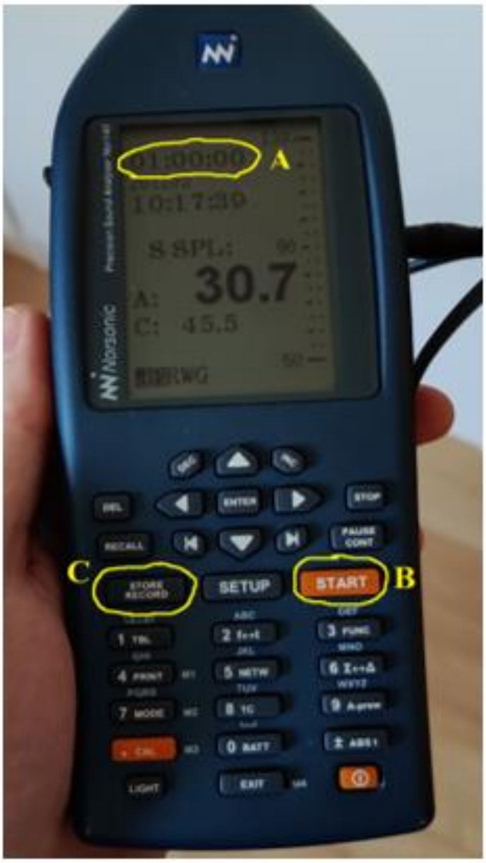
Tack för deltagandet!

Instructions for measurement:

1. Place the measurement device about two metres away from where you work. The device should not be placed right next to a wall or hard surface

2. Connect the power supply cable in the hatch on the right side of the device

3. The device will start and look like this when it has finished loading:



4. Measuring:

A: Shows the time setting for the measurement. Should not need to be modified

B: To start up the measurements, just need to press the START button. The measurement will then finish automatically when it reaches the specified measurement time.

C: **NOTE**! Store record must be pressed after the measurement in order to save the data. If the device is turned off before this, all data is lost. Once the data is saved, today's date will be shown at the top of the screen followed by a file number that ends with the letter S.

When this is done you can pull the power cable and shut the device off with the button at the bottom right. Then the measurement is finished

If there are any problems, just call me at:

Thanks for your participation!

Hej!

Här kommer en länk till enkäten för studien av ljudmiljö vid arbete hemma. Var vänlig läs igenom instruktionerna nedan innan du påbörjar enkäten.

link to google forms

Var vänlig svara på enkäten senast den 19e februari.

Syfte

Syftet med studien är att undersöka hur ljudnivå och ljudmiljö påverkar känslan av att arbeta hemifrån. Det finns i nuläget inte speciellt mycket forskning relaterad till ljudmiljö i bostaden under arbetstid, och inte heller vilka ljud som upplevs mer störande än andra under tiden man arbetar.

Instruktioner

Enkäten är uppdelad i fyra delar, och borde ta ungefär 10-15 minuter att fylla i. Känner du att du inte vill fylla i någon fråga är det okej att hoppa över den. Det föredras om du fyller i enkäten vid samma plats som du normalt sitter vid när du arbetar hemifrån. En del av frågorna kommer beröra dina åsikter om kontoret, detta syftar **enbart** på Swecos kontor, så ifall du arbetar deltid på någon annan arbetsplats bes du att endast reflektera över miljön på Swecos kontor i Malmö.

Datahantering

Undersökningen är anonym och inga personliga åsikter kommer att publiceras eller föras vidare till vare sig LTH eller Sweco. En personlig länk till enkäten skickas, men enbart i det syfte att kunna jämföra korrekt mätvärde med svaren från enkäten. Resultat från studien kommer publiceras som ett examensarbete via LTH.

Resultat av studien

Studien kommer slutföras under våren 2021. Ifall du vill ta del av resultatet kan du begära det via mail, så kommer en kopia av rapporten att mailas över när den är färdigställd. Individuella data kan även ges tillgång till vid förfrågan.

Tack för deltagandet

Appendix B: Swedish Questionnaire

Studie av ljudmiljö hemma på arbetstid

Först kommer några frågor om ditt arbete. Fyll helst i enkäten sittandes på den plats där du oftast arbetar hemifrån.

1. Jobbar du heltid?

Markera endast en oval.

- Ja
- Nej, hela dagar men inte alla dagar i veckan
- Nej, kortare dagar

2. Hur stor del av din arbetstid jobbar du hemifrån nu?

Markera endast en oval.

- 0-20%
- 20-40%
- 40-60%
- 60-80%
- 80-100%

3. Hur stor del av din arbetstid jobbade du hemifrån innan utbrottet av Covid-19?

Markera endast en oval.

- 0-20%
- 20-40%
- 40-60%
- 60-80%
- 80-100%

4. Var anser du att du får mest arbete uträttat?

Markera endast en oval.

	1	2	3	4	5	
Kontoret	◯	◯	◯	◯	◯	Hemma

Appendix B: Swedish Questionnaire

5. Var känner du att den mest bekväma arbetsmiljön finns?

Markera endast en oval.

	1	2	3	4	5	
Kontoret	⬭	⬭	⬭	⬭	⬭	Hemma

6. Var arbetar du helst?

Markera endast en oval.

	1	2	3	4	5	
Kontoret	⬭	⬭	⬭	⬭	⬭	Hemma

7. När du är på kontoret, var sitter du oftast och arbetar?

Markera endast en oval.

- ⬭ Cellkontor
- ⬭ Fast plats
- ⬭ Flexplats
- ⬭ Activity-based workstation (AWB)
- ⬭ Tyst zon
- ⬭ Möte-/Samtalsrum

8. När du är på kontoret, var föredrar du att sitta och arbeta?
Du kan välja ett alternativ som du inte har tillgång till

Markera endast en oval.

- ⬭ Cellkontor
- ⬭ Fast plats
- ⬭ Flexplats
- ⬭ Activity-based workstation (AWB)
- ⬭ Tyst zon
- ⬭ Möte-/Samtalsrum

9. När du sitter i möte, hur mycket anser du att du blir störd?

Markera endast en oval per rad.

	Inte alls	Något	Ganska mycket	Mycket	Oerhört
Hemma	⬭	⬭	⬭	⬭	⬭
På kontoret	⬭	⬭	⬭	⬭	⬭

Appendix B: Swedish Questionnaire

10. Hur mycket har du ändrat på dina arbetstider och arbetsrutiner när du arbetar hemifrån?

Markera endast en oval.

- Inte alls
- Något
- Ganska mycket
- Mycket
- Oerhört

11. Har du någon gång ändrat din arbetstid på grund av buller när du jobbat hemifrån?

Markera endast en oval.

- Ja
- Nej

12. Om du svarade ja på föregående fråga, vilka ljud var anledningen till dessa ändringar?

13. Har du någon gång ändrat din arbetstid på grund av buller när du jobbat på kontoret?

Markera endast en oval.

- Ja
- Nej

14. Om du svarade ja på föregående fråga, vilka ljud var anledningen till dessa ändringar?

Frågor om hemmet

Här kommer några frågor om personer i hushållet och rummet du brukar arbeta i när du arbetar hemmifrån

15. Vilken typ av hus bor du i?

Markera endast en oval.

- Flerbostadshus
- Radhus
- Villa/enfamiljshus

16. På vilken våning arbetar du?

Markera endast en oval.

- Bottenvåning
- Högst upp
- Mellanvåning

17. Vilket våningsnummer bor du på? (om du bor i lägenhet)

____

18. Hur stor är din bostad? Svara i kvadratmeter

____

19. Vilken typ av rum brukar du arbeta i?

Markera endast en oval.

- Sovrum
- Kök
- Vardagsrum
- Hemmakontor (rum anpassat som arbetsrum)
- Övrigt: __________________________________

20. Ifall du svarade hemmakontor på föregående fråga, användes detta som hemmakontor även innan Covid-19? (hoppa över denna fråga om du svarade något annat)

Markera endast en oval.

- Ja
- Nej

21. Hur stort är rummet du oftast arbetar i hemifrån? Svara i kvadratmeter

____

22. Brukar du stänga om dig när du arbetar?

Markera endast en oval.

- Ja
- Nej, öppen dörr
- Nej, finns inga dörrar att stänga

Appendix B: Swedish Questionnaire

23. Har rummet fönster som vetter mot något av följande?
Du kan välja flera alternativ

Markera alla som gäller.

- [ ] Gång- och cykelväg
- [ ] Mindre bilväg
- [ ] Landsväg
- [ ] Motorväg
- [ ] Järnväg/spårväg
- [ ] Gård/parkområde
- [ ] Affärer/annan verksamhet

24. Finns det några husdjur i hushållet?

Markera endast en oval.

- ◯ Ja
- ◯ Nej

25. Hur många personer bor i hushållet?

____

26. Hur många av dessa är barn, och vad är deras åldrar?

____

27. Hur många vuxna brukar vara hemma under tiden du arbetar hemifrån, inklusive dig själv?

____

28. Hur många barn brukar vara hemma under tiden du arbetar hemifrån?

____

Frågor om Buller

De följande frågorna om buller berör enbart tiden du arbetar. Buller syftar här på oönskat och/eller störande ljud.

29. Hur mycket anser du dig störas av buller?
0 är inte alls och 10 är oerhört mycket (Du kan behöva scrolla åt höger för att se samtliga alternativ)

Markera endast en oval per rad.

	0	1	2	3	4	5	6	7	8	9	10
Hemma	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯
På kontoret	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯

Appendix B: Swedish Questionnaire

30. Hur vanligt förekommande är störande ljud när du arbetar?

Markera endast en oval per rad.

	Inte alls	Något	Ganska mycket	Mycket	Oerhört
Hemma	⬭	⬭	⬭	⬭	⬭
På kontoret	⬭	⬭	⬭	⬭	⬭

31. Hur mycket känner du att du tappar koncentrationen när du arbetar på grund av buller

Markera endast en oval per rad.

	Inte alls	Något	Ganska mycket	Mycket	Oerhört
Hemma	⬭	⬭	⬭	⬭	⬭
På kontoret	⬭	⬭	⬭	⬭	⬭

32. Hur mycket anser du att buller från följande källor stör när dig när du arbetar hemifrån?
0 är ingen störning alls och 10 är oerhört störande (Du kan behöva scrolla åt höger för att se samtliga alternativ)

Markera endast en oval per rad.

	0	1	2	3	4	5	6	7	8	9	10
Trafik	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭
Underhållsarbete (lövblås, gräsklippningm, soptömning etc)	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭
Husdjur	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭
Grannar	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭
Byggarbeten	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭
Ljud från innegård/uteplats	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭
Ventilationssystem	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭
Vattenledningar	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭
Barn i hemmet	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭
Andra vuxna i hemmet	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭
Elektronik i hushållet	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭

33. Är det några störande bullerkällor som inte togs upp? I så fall, skriv upp dessa och hur störande du anser dem vara

Appendix B: Swedish Questionnaire

34. Gör du något av följande för att stänga ute buller när du arbetar?

Kryssa i både rutorna för kontoret och hemma ifall du gör det på båda platserna

Markera alla som gäller.

	Ja, hemma	Ja, på kontoret	Nej, inte alls
Lyssnar på musik	☐	☐	☐
Spelar upp maskerande ljud (white noise, pink noise, naturljud etc)	☐	☐	☐
Använder någon form av hörselskydd	☐	☐	☐

Avslutningsvis, några frågor om dig

35. Vilket år är du född? Ange 4 siffror

____

36. Vilket är ditt kön?

Markera endast en oval.

- Man
- Kvinna
- Annat
- Vill ej svara

37. Hur många år har du arbetat med ditt nuvarande yrke?

____

38. Hur många år har du arbetat på Sweco?

____

39. Hur tar du dig oftast till kontoret i nuläget?

Markera endast en oval.

- Bil
- Kollektivtrafik
- Cykel/gång
- Jag tar mig inte till kontoret nu
- Övrigt: ________________________

Appendix B: Swedish Questionnaire

40. Hur tog du dig oftast till kontoret före Covid-19?

Markera endast en oval.

- ◯ Bil
- ◯ Kollektivtrafik
- ◯ Cykel/gång
- ◯ Övrigt: ____________________

41. Hur skulle du beskriva din känslighet för ljud?

Markera endast en oval.

- ◯ Inte alls
- ◯ Något
- ◯ Ganska mycket
- ◯ Mycket
- ◯ Oerhört

42. Använder du hörapparat?

Markera endast en oval.

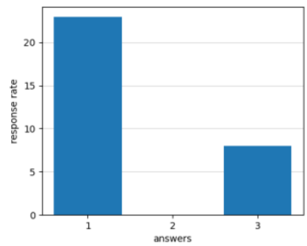
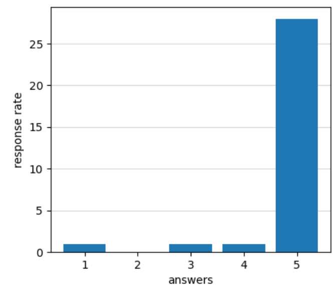
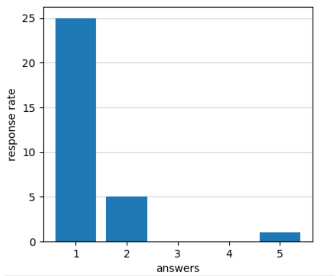
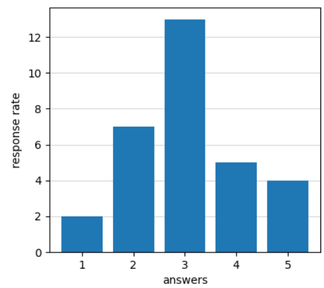
- ◯ Ja
- ◯ Nej

43. Hade du velat fortsätta jobba mer hemifrån även efter att restriktionerna har släppts?

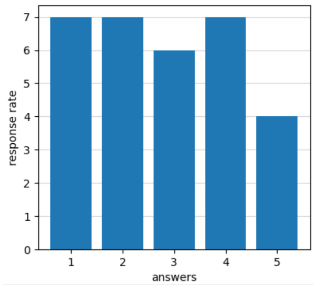
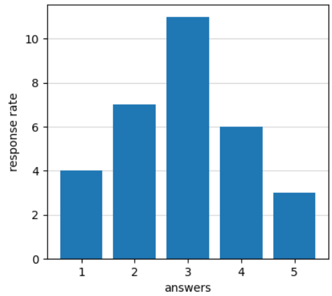
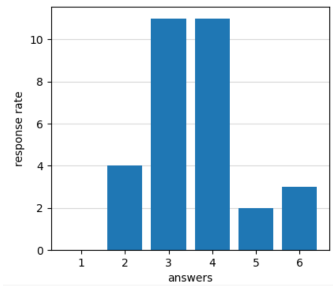
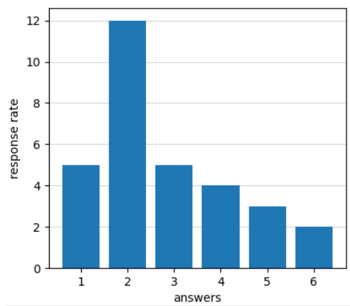
Markera endast en oval.

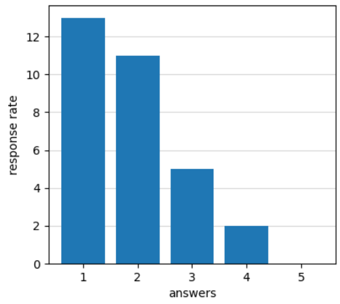
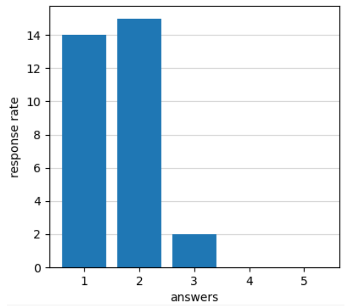
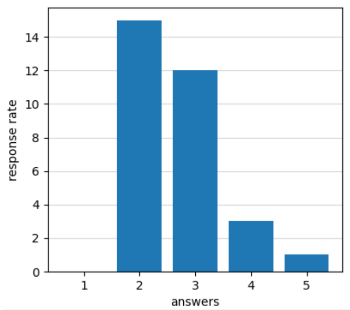
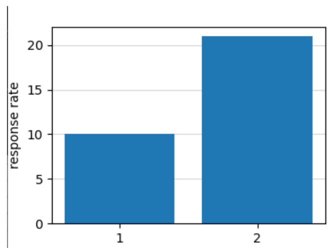
- ◯ Ja, ännu mer än nu
- ◯ Ja, som jag jobbar nu
- ◯ Det går bra vilket som
- ◯ Nej, som det var innan
- ◯ Jag vill inte jobba hemifrån alls

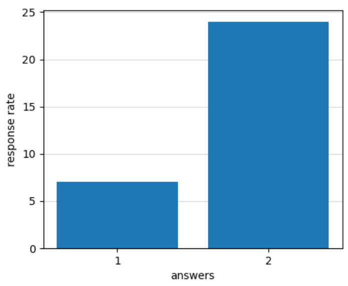
Appendix C: Questionnaire results

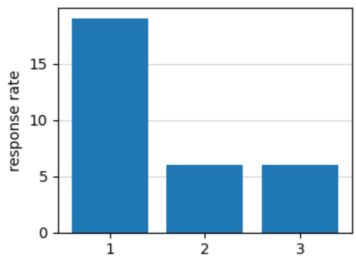
<table>
<tr><th colspan="2">Section 1: Work-related questions</th><th>Result graphs</th></tr>
<tr><td>1. Do you work full-time?
n=31</td><td>1: Yes
2: No, full days but not all days
3: No, not full days</td><td>
</td></tr>
<tr><td>2. About how much of your work do you do from home?
n=31</td><td>1: 0-20%
2: 20-40%
3: 40-60%
4: 60-80%
5: 80-100%</td><td>
</td></tr>
<tr><td>3. About how much of your work did you do from home before Covid-19?
n=31</td><td>1: 0-20%
2: 20-40%
3: 40-60%
4: 60-80%
5: 80-100%</td><td>
</td></tr>
<tr><td>4. Where do you feel you get the most work done in a day's work?
n=31</td><td>A scale of 1 (office) to 5 (at home)</td><td>
</td></tr>
</table>

Appendix C: Questionnaire results

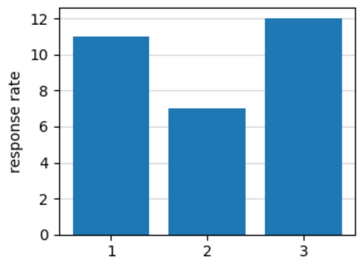
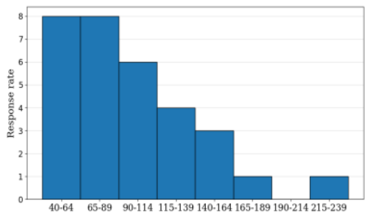
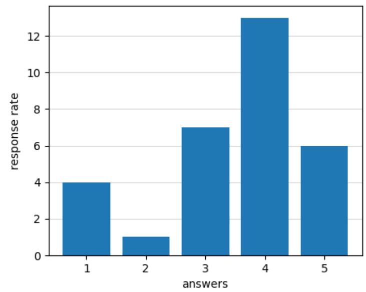
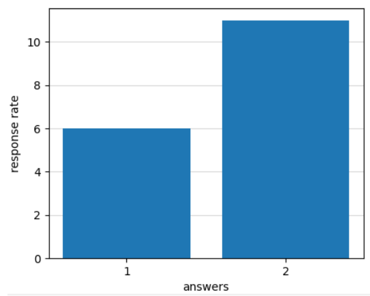
5. Where do you feel the most comfortable working environment is? n=31	A scale of 1 (office) to 5 (at home)	
6. Where do you prefer to work? n=31	A scale of 1 (office) to 5 (at home)	
7. When you are at the office, where do you usually sit and work? n=31	1: Cell office 2: Fixed seat 3: Flexible workspace 4: Activity-based workstation 5: Quiet zone 6: Meeting-/ or conference room	
8. When you are at the office, where do you prefer to sit and work? n=31	1: Cell office 2: Fixed seat 3: Flexible workspace 4: Activity-based workstation 5: Quiet zone 6: Meeting-/ or conference room	

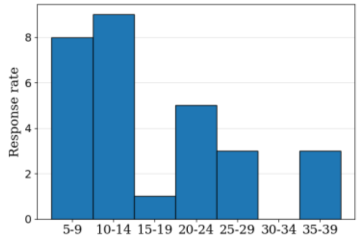
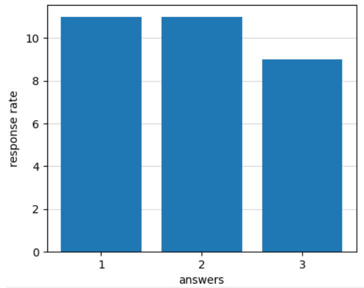
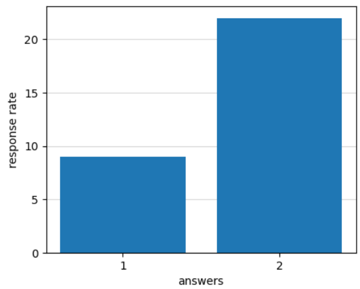
9. If you are in a meeting, how often are you disturbed at home? n=31	1: Not at all 2: Somewhat 3: Fairly 4: Very 5: Extremely	
9b. If you are in a meeting, how often are you disturbed at the office? n=31	1: Not at all 2: Somewhat 3: Fairly 4: Very 5: Extremely	
10. How much have you changed your working hours and working routine in general when working from home? n=31	1: Not at all 2: Somewhat 3: Fairly 4: Very 5: Extremely	
11. Have you ever changed your working hours because of noise when working from home? n=31	1: Yes 2: No	

12. If you answered yes on the previous question, what noises caused you to do these changes? n=10	Written text	
13. Have you ever changed your working hours because of noise when working at the office? n=31	1: Yes 2: No	
14. If you answered yes on the previous question, what noises caused you to do these changes? n=6	Written text	

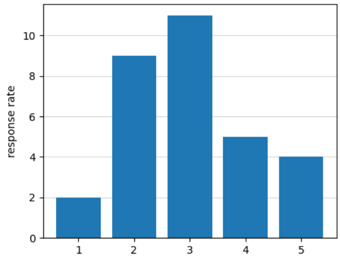
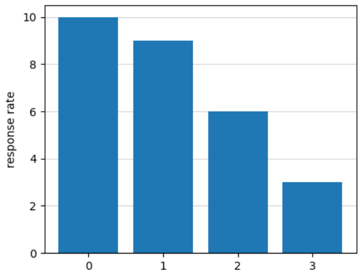
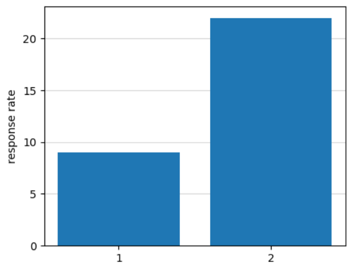
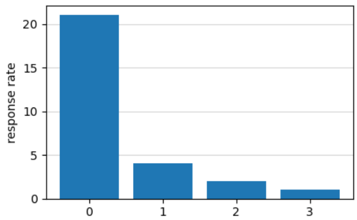
Section 2: Questions about dwelling		Result graphs
15. What type of building do you live in? n=31	1: Apartment building 2: Terraced house 3: Detached house	

Appendix C: Questionnaire results

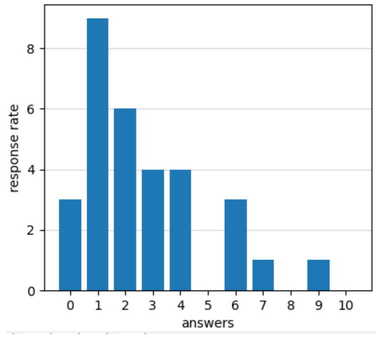
16. On what kind of floor do you work? n=30	1: Ground floor 2: Top floor 3: Middle floor	
17. What floor number do you live on? n=19	Written text	
18. What is the size of your dwelling? Answer in square metres n=31	Written text	
19. What kind of room do you usually work from? n=31	1: Bedroom 2: Kitchen 3: Living room 4: Home office 5: Other	
20. If you answered home office on the previous question, was this room used as a home office before Covid-19 aswell? n=17	1: Yes 2: No	

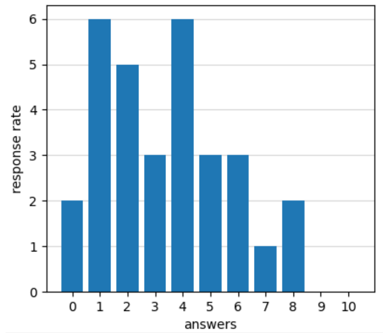
21. What is the size of the room you are working from? Answer in square metres n=31	Written text	
22. Do you usually shut the door when working from home? n=31	1: Yes 2: No, open door 3: No, there are no doors to close	
23. Does the room have windows that face any of the following: (More than one can be selected)	Cycle path / Smaller car road / Main road / Motorway / Train or tram track / Yard or park / Shops or other activity	
24. Are there any pets in the household? n=31	1: Yes 2: No	

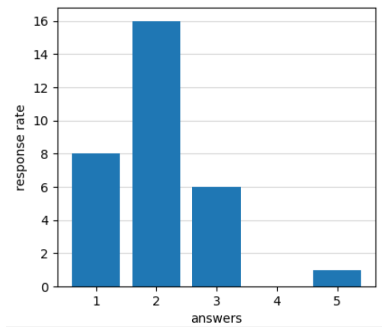
Appendix C: Questionnaire results

25. Including you, how many people live in the household? n=31	Written text	
26. How many of these are children, and what are their ages? n=28	Written text	
27. Including you, how many adults use to be at home while you are working from home? n=31	Written text	
28. How many children use to be at home while you are working from home? n=28	Written text	

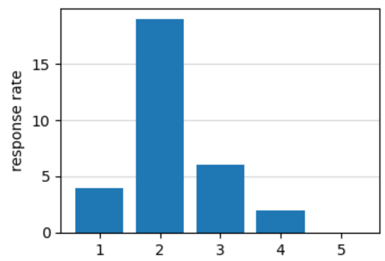
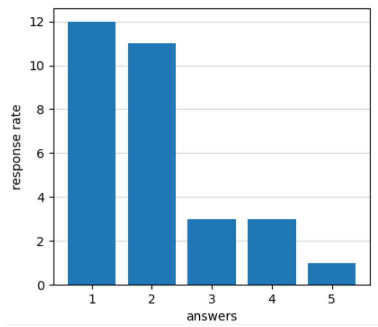
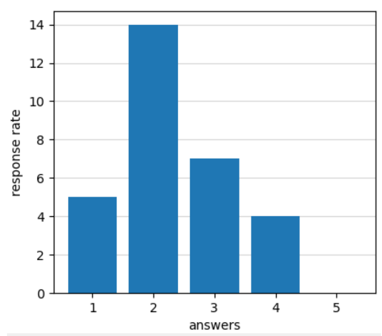
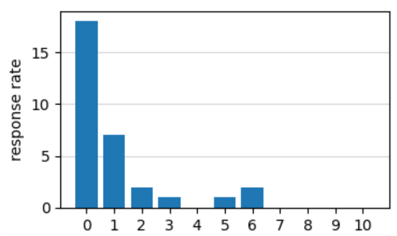
<table>
<tr><th colspan="2">Section 3: Questions about noise</th><th>Result graphs</th></tr>
<tr><td>29a. How much are you disturbed by noise in general at home?

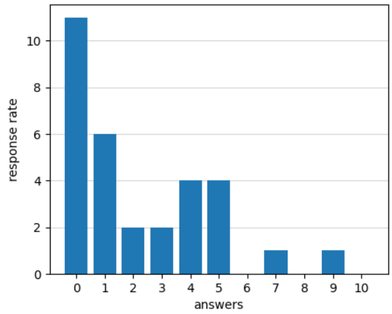
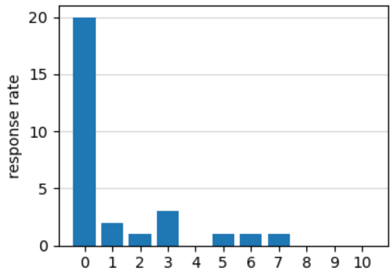
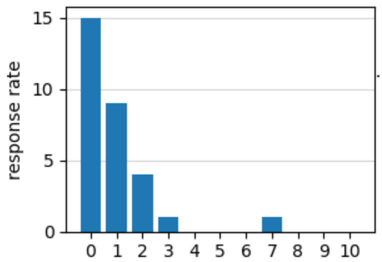
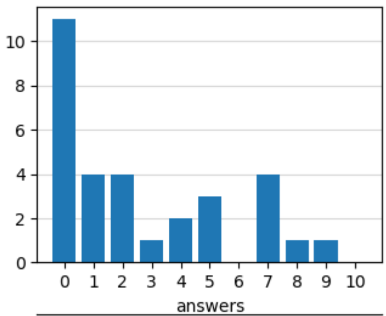
n=31</td><td>Scales of 0 to 10</td><td>
</td></tr>
<tr><td>29b How much are you disturbed by noise in general at the office?

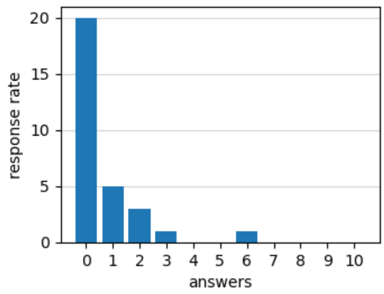
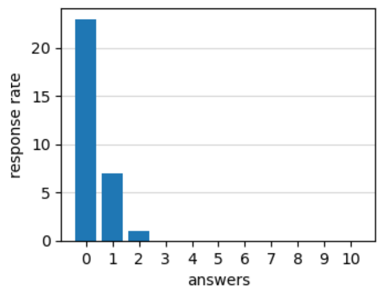
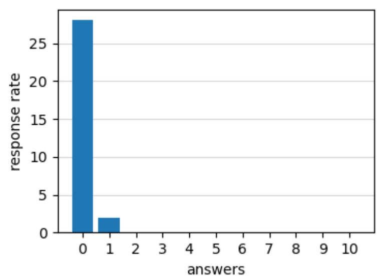
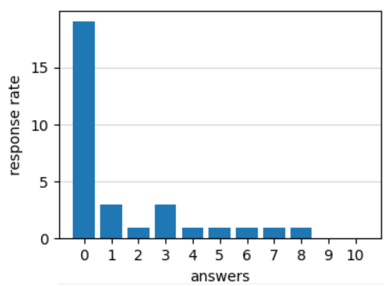
n=31</td><td>Scales of 0 to 10</td><td>
</td></tr>
<tr><td>30a. How often do disturbing noises occur when you are working at home?

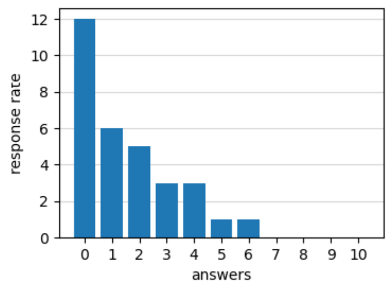
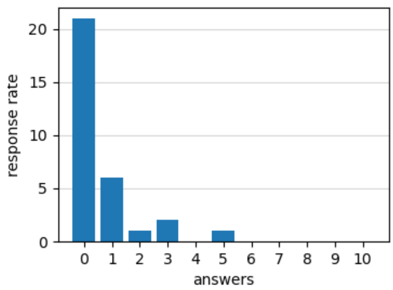
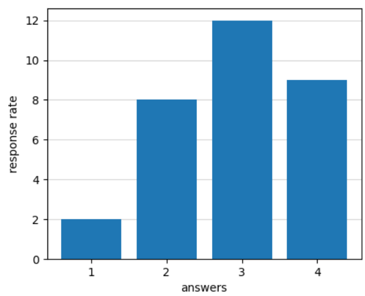
n=31</td><td>1: Not at all
2: Somewhat
3: Fairly
4: Very
5: Extremely</td><td>
</td></tr>
</table>

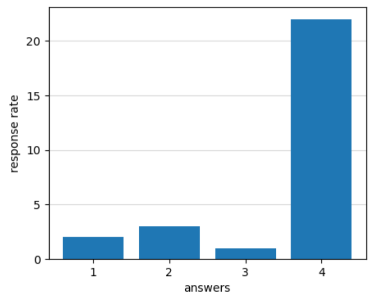
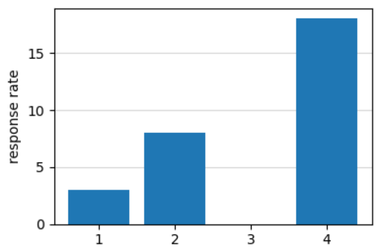
Appendix C: Questionnaire results

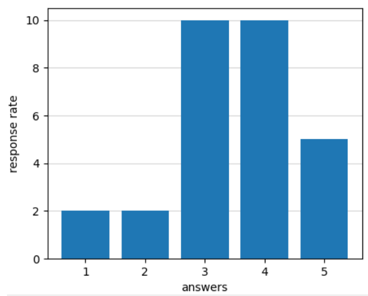
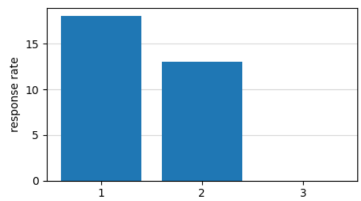
30b. How often do disturbing noises occur when you are working at the office? n=31	1: Not at all 2: Somewhat 3: Fairly 4: Very 5: Extremely	
31a. How much do you feel you lose concentration due to noise when working at home? n=30	1: Not at all 2: Somewhat 3: Fairly 4: Very 5: Extremely	
31b. How much do you feel you lose concentration due to noise when working at the office? n=30	1: Not at all 2: Somewhat 3: Fairly 4: Very 5: Extremely	
32a. How much are you disturbed by noise from following sources? Traffic n=31	Scales of 0 (never) to 10 (extremely often)	

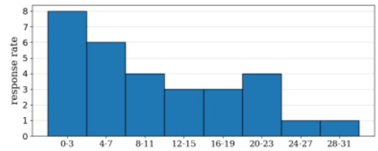
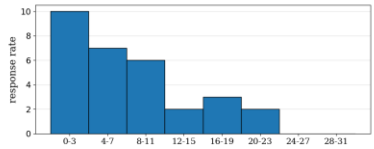
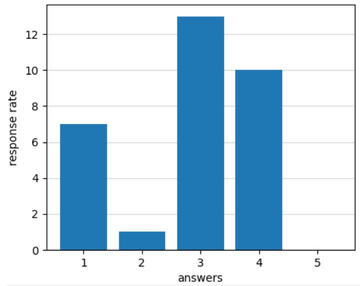
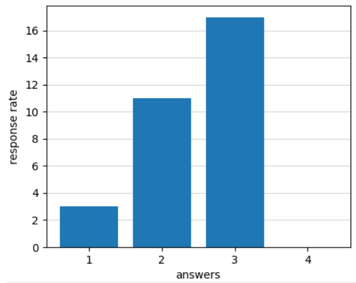
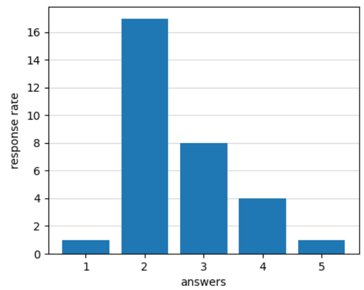
32b. Maintenance work n=31		
32c. Pets n=29		
32d. Sound from neighbours n=30		
32e. Construction work n=31		

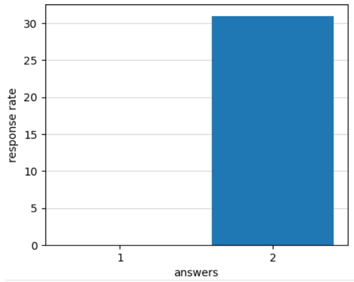
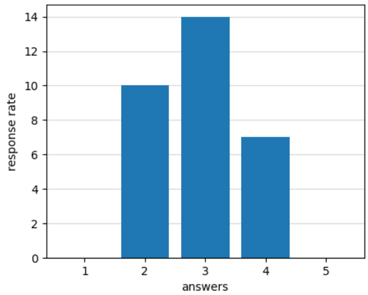
32f. Sound from courtyard n=30		
32g. Ventilation system n=31		
32h. Water pipes n=30		
32i. Children in the house n=31		

32j. Other adults in the house n=31		
32k. Household electronics n=31		
33. Are there any disturbing noise sources that was not provided as an option? In that case, feel free to write the source and a value of disturbance n=3	Written text	
34a. Do you usually listen to music to shut out noise? n=31	1. Yes, at home 2. Yes, at the office 3. Both at home and office 4. No	

34b. Do you usually list to masking noise to shut out noise? n=28	1. Yes, at home 2. Yes, at the office 3. Both at home and office 4. No	
34c. Do you usually use any form of hearing protection to shut out noise? n=29	1. Yes, at home 2. Yes, at the office 3. Both at home and office 4. No	

Section 4: Personal questions		**Result graphs**
35. Year of birth? Answer with 4 digits n=29	1: 1950s, 2: 1960s, 3: 1970s, 4: 1980s, 5: 1990s	
36. What is your gender? n=31	1: Male 2: Female 3: Other	

37. For how many years have you been working with your current occupation? n=31	Written text	
38. For how many years have you been working at Sweco? n=31	Written text	
39. How do you usually get to the office nowadays? (With Covid-19 restrictions) n=31	1: Car 2: Public transportation 3: Bike or walking 4: I do not go to the office now 5: Other	
40. How did you usually get to the office before Covid-19? n=31	1: Car 2: Public transportation 3: Bike or walking 4: Other	
41. How would you describe your sensitivity to sound? n=31	1: Not at all 2: Somewhat 3: Fairly 4: Very 5: Extremely	

42. Do you use hearing aid? n=31	1: Yes 2: No	
43. Would you like to work more from home after the restrictions are gone? n=31	1: Yes, more than now 2: Yes, as I do now 3: Either way is okay 4: No, as before 5: I do not want to work from home at all	

Appendix D: Correlation tables

Spearman r-values, orange = p<0,05

	Q4	Q5	Q6	Q10	Q18	Q21	Q25	Q26	Q27	Q28	Q27+Q28	Q29a
Q4		0,43	0,70	-0,28	0,42	0,02	0,00	-0,01	0,21	-0,30	-0,06	-0,32
Q5	0,43		0,70	-0,16	0,03	-0,09	0,02	0,08	0,13	-0,10	-0,01	-0,18
Q6	0,70	0,70		-0,07	0,14	-0,03	0,00	-0,11	0,25	-0,42	-0,08	-0,26
Q10	-0,28	-0,16	-0,07		-0,23	-0,17	-0,17	-0,35	-0,14	-0,20	-0,17	0,14
Q31a	-0,15	0,05	-0,13	0,03	0,08	0,20	0,36	0,26	0,42	0,32	0,49	0,60
Q31b	0,12	0,34	0,10	0,53	-0,14	-0,20	-0,22	-0,18	-0,16	-0,15	-0,26	0,01
Q41	0,06	0,26	0,13	0,00	0,05	-0,19	-0,04	-0,04	0,01	-0,15	-0,17	-0,04

	Q29b	Q29a-Q29b	Q31a	Q31b	Q32a	Q32b	Q32c	Q32d	Q32e	Q32f	Q32g
Q4	0,15	-0,35	-0,15	0,12	-0,07	-0,39	-0,23	-0,42	-0,30	-0,35	0,24
Q5	0,13	-0,18	0,05	0,34	-0,04	-0,36	-0,17	-0,37	-0,24	-0,25	0,04
Q6	-0,13	-0,10	-0,13	0,10	-0,22	-0,33	-0,15	-0,42	-0,27	-0,33	0,11
Q10	0,16	-0,06	0,03	0,53	-0,01	0,24	0,40	0,27	0,27	0,15	-0,02
Q31a	-0,23	0,55		-0,02	0,01	-0,03	0,11	-0,01	0,24	0,20	0,22
Q31b	0,68	-0,51	-0,02		0,08	0,08	0,15	0,11	0,13	0,04	0,11
Q41	0,28	-0,22	0,32	0,45	0,06	-0,07	-0,16	-0,10	0,13	-0,13	0,18

	Q32h	Q32i	Q32j	Q32k	Q35	Q37	Q38	Q41	Commute t	Leq	La90
Q4	-0,23	-0,27	-0,40	-0,04	0,26	0,29	0,16	0,06	0,16	-0,09	-0,17
Q5	-0,26	0,07	-0,13	0,00	-0,20	-0,04	-0,04	0,26	-0,05	-0,10	-0,01
Q6	-0,35	-0,24	-0,34	-0,06	-0,04	-0,01	-0,08	0,13	0,23	-0,11	-0,11
Q10	-0,05	-0,09	0,11	0,20	-0,32	-0,20	-0,20	0,00	0,00	0,04	0,01
Q31a	0,20	0,31	0,41	-0,04	-0,25	-0,14	-0,10	0,32	-0,52	0,04	0,37
Q31b	0,07	-0,04	0,14	0,36	-0,45	-0,20	-0,20	0,45	-0,13	-0,07	-0,10
Q41	0,00	-0,10	0,21	0,09	-0,43	-0,25	-0,14		-0,26	-0,27	0,01

Appendix D: Correlation tables

Pearson r-values, orange = p<0,05	Q18	Q21	Q25	Q26	Q27	Q28	Q27+Q28	Q29a	Q29b	Q29a-Q29b	Q32a	Q32b	Q32c	Q32d
Q18														
Q21	-0,01													
Q25	0,68	0,05												
Q26	0,67	0,01	0,89											
Q27	0,36	0,01	0,45	0,37										
Q28	0,05	0,07	0,55	0,43	0,08									
Q27+Q28	0,25	0,04	0,67	0,54	0,59	0,88								
Q29a	-0,17	-0,05	0,07	0,00	0,30	0,28	0,33							
Q29b	-0,13	-0,06	-0,31	-0,15	-0,30	-0,03	-0,22	-0,05						
Q29a-Q29b	-0,02	0,01	0,26	0,10	0,41	0,21	0,38	0,72	-0,73					
Q32a	-0,15	-0,29	-0,14	-0,18	0,04	0,17	0,17	0,16	-0,01	0,12				
Q32b	-0,39	-0,20	-0,33	-0,36	-0,10	-0,14	-0,14	0,23	-0,01	0,16	0,53			
Q32c	-0,35	-0,10	-0,20	-0,32	-0,32	0,18	-0,11	0,30	0,21	0,05	0,30	0,43		
Q32d	-0,29	-0,10	-0,21	-0,51	0,01	0,08	0,00	0,39	0,11	0,18	0,30	0,31	0,09	
Q32e	-0,16	-0,43	-0,15	-0,18	-0,12	-0,01	-0,05	0,47	-0,14	0,42	0,42	0,60	0,45	0,07
Q32f	-0,33	-0,17	-0,26	-0,30	0,17	0,06	0,16	0,40	-0,04	0,29	0,65	0,71	0,49	0,45
Q32g	0,21	0,22	0,06	-0,04	0,08	0,13	0,16	0,03	0,29	-0,19	-0,04	-0,02	0,20	-0,06
Q32h	-0,09	0,01	0,02	0,00	-0,12	0,33	0,19	0,12	0,08	0,03	0,24	0,42	0,41	0,21
Q32i	0,17	0,02	0,52	0,55	0,37	0,66	0,73	0,10	-0,08	0,13	0,17	-0,02	-0,11	-0,08
Q32j	-0,05	-0,09	0,23	0,26	0,12	0,53	0,40	0,50	0,17	0,22	0,25	0,24	0,50	0,43
Q32k	-0,32	-0,04	-0,33	-0,34	-0,09	0,00	-0,04	0,09	0,18	-0,07	0,38	0,36	0,13	0,16
Q35	0,13	0,14	-0,03	0,09	0,02	0,07	0,03	-0,41	-0,17	-0,17	-0,20	-0,27	-0,21	-0,16
Q37	0,34	-0,23	0,21	0,16	0,06	0,16	0,18	-0,27	-0,18	-0,06	-0,02	-0,19	-0,11	-0,10
Q38	0,41	-0,08	0,34	0,27	0,03	0,28	0,25	-0,28	-0,12	-0,11	-0,02	-0,25	0,00	-0,19
Commute	-0,12	-0,07	-0,17	-0,10	-0,11	-0,40	-0,37	-0,22	-0,03	-0,13	-0,43	0,03	-0,20	0,03
LAeq	-0,08	-0,36	0,07	-0,03	0,10	0,28	0,30	-0,10	-0,36	0,18	0,26	0,08	-0,15	-0,11
La90	-0,11	-0,28	0,11	0,04	0,33	0,25	0,38	0,30	-0,15	0,31	0,21	0,09	-0,03	0,11

	Q32e	Q32f	Q32g	Q32h	Q32i	Q32j	Q32k	Q35	Q37	Q38	Commute	Leq	La90
Q32e													
Q32f	0,38												
Q32g	-0,07	0,03											
Q32h	0,32	0,28	0,38										
Q32i	0,03	0,07	0,03	0,34									
Q32j	0,20	0,33	0,26	0,57	0,47								
Q32k	0,02	0,34	0,24	0,31	0,05	0,24							
Q35	-0,40	-0,10	-0,18	-0,10	-0,09	-0,38	-0,17						
Q37	-0,24	-0,03	-0,18	-0,02	0,03	-0,22	-0,11	0,72					
Q38	-0,28	-0,09	-0,06	0,10	0,15	-0,07	-0,15	0,60	0,84				
Commute	-0,26	-0,11	-0,04	-0,26	-0,37	-0,37	-0,04	0,27	0,10	-0,01			
LAeq	0,08	0,20	-0,30	-0,02	0,32	-0,12	0,21	0,28	0,41	0,28	0,05		
La90	0,38	0,30	-0,04	-0,06	0,30	0,02	0,01	-0,05	-0,08	-0,27	-0,02	0,41	