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Acoustic Environment in Wooden Offices

A Comparison of Perceived Sound Environment Between Wooden and Concrete Office Buildings

Master's thesis in Sound and Vibration

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Cover: Picture of wooden beams in the office building Nodi, Nya Hovås.

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Abstract

Building in wood is becoming increasingly popular, and acousticians face new challenges regarding the indoor sound environment. The knowledge about the acoustic environment in wooden offices is not meeting the increasing demand, hence more studies on the subject are needed. Up till now, most office buildings are constructed in concrete, but a shift in mindset within the building industry has created already noticeable changes towards constructing larger buildings in wood. This thesis investigates the acoustic environment in wooden offices to identify differences in wooden and concrete buildings, find correlations between the perceived acoustic quality and the measured, as well as learn how the employees in the office perceive the acoustic environment. The thesis is made in collaboration with Efterklang part of AFRY.

A total of eight offices located in different parts of Sweden have been investigated, out of which four are wooden buildings. The methods used to investigate the problem formulation are a questionnaire survey, an analysis of collected available measurement data for the buildings and a literature study. The questionnaire survey was distributed to employees in the eight buildings, and aimed to learn how they perceived the acoustic environment of their office. In the literature study differences between the acoustics in wooden and concrete constructions were identified. For wooden constructions it is impact noise and low frequency sounds that are a common problem, while the sound insulation at high frequencies usually is good. For concrete buildings these problems are not as common due to a larger amount of existing knowledge. In the results from the questionnaire and collected available measurement data it was shown that the employees overall perceive their offices to have a good acoustic environment. It was also found that the most disturbing source, regardless of building type, are colleagues talking on the phone (including Teams, Zoom etc.) and colleagues talking to each other. Impact noise was chosen by a third of the respondents in the wooden offices as one of the more disturbing sources, but a fourth of the respondents answered that they were not disturbed by anything. Overall the responses show a positive view on the acoustics in wooden offices.

Keywords: acoustic environment, wooden office buildings, concrete office buildings, sound perception, questionnaire survey

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1

Introduction

The subject of this master thesis was suggested by Krister Larsson and Andreas Colebring at Efterklang part of AFRY. The aim and method were decided in collaboration between the students performing this thesis and Efterklang. In this chapter the subject of the thesis is presented along with the problem formulation. This is followed by a description of the aim of the work and the decided demarcations.

1.1 Problem Description

Concrete have long played a big role as the most common building material, but from a sustainability perspective, it is time to move on and start thinking about constructing more wooden structures. This development sets new demands on the acoustic environment inside wooden offices and more knowledge about the subject is needed. Thereby it becomes important to investigate the acoustics and determine how it differs from the more common offices built in concrete, as well as determine the benefits or drawbacks of working in wooden buildings.

When regarding acoustics in wooden buildings most studies focus on residential buildings while the knowledge in a working environment is limited. To fully understand the acoustic environment inside a wooden office it becomes important to investigate how the workers perceive the acoustic quality in the working space. This can also give a better picture of which sounds that can be seen as disturbing and how the sound environment is understood as a whole. This thesis work is carried out to increase the knowledge regarding acoustics in wooden offices.

1.2 Problem Formulation

The problem description thus leads to the following questions:

- What are the acoustic differences between wooden- and concrete offices?
- What is the correlation between the perceived acoustic qualities and the measured acoustic parameters in a wooden office?
- How is the acoustic environment in wooden offices perceived by the people working there?

1.3 Aim

The aim of the thesis work is to investigate the acoustic environment in wooden offices to identify differences between offices in wooden buildings compared to concrete buildings. It should also be investigated if there exists a correlation between the perceived acoustic quality and the measured acoustic parameters in wooden offices. In addition it will be studied how employees in the offices perceive the acoustic environment.

1.4 Demarcations

The thesis work includes studies of both wooden- and concrete buildings, but the main focus is to investigate the acoustic environment in wooden offices. Hence the results will be confined to wooden offices and the knowledge about the acoustic environment in concrete offices will only be used for comparison.

To keep the thesis at a feasible level, the work will be constricted to study the acoustic environment only in offices. The acoustic environment in residential wooden buildings will not be considered, but will be studied in the literature study to gain general knowledge of how acoustics in wooden buildings work and which regulations that exists. The acoustic environment in other types of premises (schools, healthcare facilities, industry etc.) is outside the scope of the thesis.

Another clear demarcation is that the thesis work only aims to find how the acoustic environment in wooden offices is perceived, and increase the knowledge of how the acoustic environment in wooden offices works. No suggestions of improvements will be studied or proposed in this project, since this is beyond the scope of the work and time limit.

The thesis will be limited to only study the parameters and aspects connected to the area of sound and noise to reduce the size of the project. Vibrations will therefore not be regarded in this report.

For the investigation of Trafikverkets Headquarters in Borlänge the analysis of the results is limited to the comparison only. This is due to the construction being a mixture of old buildings in concrete and a newly built connection in wood.

2

Theory

The theory chapter is based on a literature study that aims to give a background to the studied subject. It will also give an understanding of the methods used to obtain results from wooden and concrete offices that are in use today.

2.1 Building Acoustics

When referring to building acoustics one talks about the science of controlling noise within a building. This includes reducing noise transmission from one room to another and regulating the sound properties inside the space itself. In figure 2.1 different sound sources and transmission paths in a building is shown.

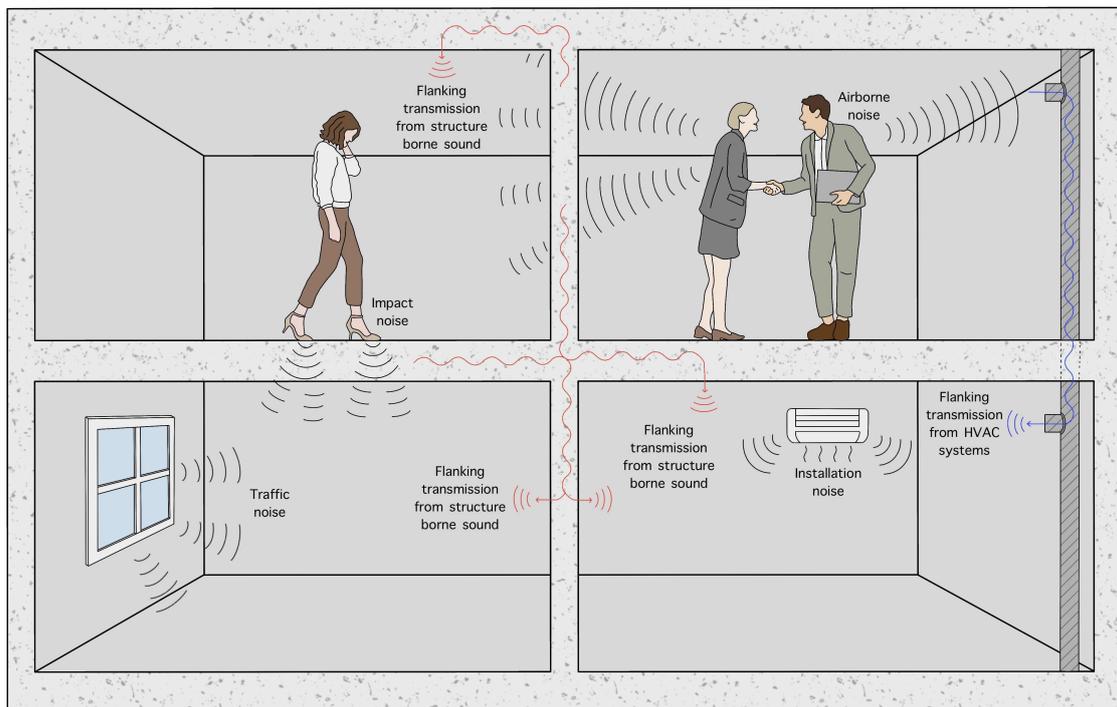


Figure 2.1: Illustration of sound sources and transmission paths in a building.

Sounds in a building are transmitted as both airborne- and structure borne noise [1]. Airborne noise is sound transmitted through the air, for example speech or music, and structure borne noise is sound transmitted through the structure of the

building in the form of vibrations [2]. Impact noise is a way to characterise structure borne noise that occurs when an object impacts on another, such as footsteps on a floor [2]. The impact results in sound being transmitted through the floor structure into the space below. In practice, airborne- and structure borne noise are mostly considered separately, however, the two phenomena are closely related. This is because airborne noise can become structure borne noise and contrariwise [1].

Sounds in a building can also be transmitted as flanking transmissions. This means that sound is transmitted indirectly through construction elements rather than directly through the main separating element [2].

Installation or building service equipment noise are sounds caused by fixed installations within a building, which can generate both airborne- and structure borne noise [3]. For example, noise from ventilation can be considered as airborne noise while vibrations from a washing machine can cause structure borne noise.

Traffic noise is sound generated by the movement of cars, trams, trains and busses, etc.. The sound from these sources can propagate from the outside through the facade or other construction elements into the building and cause disturbance [3].

An important property to take into account when studying the acoustic environment inside a room is the reverberation time. This is defined by the time it takes for the sound pressure level to decrease by 60 dB after the sound source have abruptly been switched off [4]. In other words it is a measurement of the "echo" within a room. For example, a room with a long reverberation time can be perceived as loud and noisy [4]. When regarding speech intelligibility a low reverberation time is recommended for rooms designed for speech since a long reverberation time cause worse speech recognition [5]. The preferred reverberation time for spaces designed for speech is 1.0 seconds, or less. Yet the ideal reverberation time for an office space is between 0.4 to 0.6 seconds, since this range gives a sufficient speech intelligibility and reduction of noise.

2.2 Acoustics in Wood and Concrete

Wooden buildings are lightweight constructions and concrete buildings are heavy-weight constructions. Concrete buildings are usually also homogeneous constructions, while wooden structures commonly are built up by several layers. This creates differences in the acoustical behavior of the two building types. It is important to know these differences to understand how the acoustic environment in offices can change when going from traditional concrete buildings to large wooden constructions. In this section a brief overview is given of the two materials and their acoustic properties.

2.2.1 Wooden Buildings

Building multi-storey constructions of wood in Sweden has only been allowed since the 1990s [6], why most of the office buildings today are heavyweight constructions made of concrete. It has since then been a shift in mindset within the building industry towards using more sustainable building materials, which has led to an increased interest in building larger constructions made out of wood [7]. The multi-storey wooden buildings existing today can differ a lot in the way they have been constructed, which creates challenges regarding the acoustic design since the existing prediction models are limited when applied in lightweight buildings [8].

2.2.1.1 Wood as Building Material

Wood is a renewable material which binds and stores carbon dioxide, CO₂, throughout its life cycle [9]. The growing trees in the forest binds the CO₂ and as they are cut down and transformed to wooden products the carbon dioxide is stored until the products can no longer serve its purpose and are disposed. The amount of forest in Sweden is continuously increasing [9] and today 68% of the land area is covered by forest out of which 84% can be used for wooden products [10]. Using wood in buildings, especially larger ones, means that the CO₂ in the products will be stored for a long time. This is one of the reasons why wood is a better alternative from a climate perspective.

The wooden material is strong in relation to it being lightweight, and this has several benefits during the buildings process. One example is an increased amount of prefabrication, which in turn also leads to a reduced need for transportation [9]. A reduced need for transportation leads to less traffic emissions and can be beneficial from an economical and a sustainability perspective as well. Using wood as building material also helps to reduce noise and dust at the construction site compared to other materials, and the possibility to prefabricate the pieces allows for a more ergonomic working environment during the process [9]. The construction of the buildings at the site is also much quicker, which reduces the disturbance to the surroundings.

A finished wooden construction also have positive features due to the properties of the material. One property of wooden constructions is their ability to even out the humidity indoors which positively affects the comfort. The material is hygroscopic, and can both absorb and release moisture depending on the relative humidity in the room [11].

2.2.1.2 Social Values of Wood in Buildings

Wooden buildings are not only beneficial from an environmental perspective, but they also have positive effects on the social value. Wood is a natural material and it has been found that this gives similar effects on humans as when we spend time in nature [9]. A study conducted in a hospital environment found indications of faster decreasing pain and stress levels in patient staying in wooden rooms [11].

Another study, conducted in Austria, has shown that wood in the interior increases the learning of children in schools [9].

Having visible wood in a building can also give the perception of the building being more environmentally friendly, and the material is generally perceived in a positive way [11]. People usually experience wood to be a warm and pleasant material, and thinks it is comfortable to the touch [9].

2.2.1.3 Acoustics in Wood

The acoustics in multi-storey wooden buildings is a challenge. The shift in mindset towards building in a more sustainable way causes a shortage in experience and knowledge from already existing projects, making every new building more like a blank page. The majority of the research of acoustics in wooden buildings are in addition made on residential buildings, which have different regulations and requirements compared to office buildings. Wooden buildings are lightweight constructions which imposes certain difficulties regarding the acoustics, while at the same time finding acoustic advantages with the material. The most common noise problems in lightweight wooden buildings are impact noise [8] and low frequency noise [12]. Regarding impact noise it is often the sound from foot steps that causes annoyance [8]. The character of the sound is affected by body and foot weight of the person walking, as well as the number of steps per second [13]. These properties are most important at the low frequencies, while at the high frequencies it is instead the type of shoe that matters the most. Another source of low frequency sound inside buildings is service equipment noise [8].

A challenge when doing measurements of low frequency noise indoors is the risk of wavelengths being similar to the dimensions of the room [14]. If this happens, the sound field can no longer be considered to be diffuse and the modal response influences the sound field. A way to improve the low frequency noise generated by this phenomenon is to make the joists stiffer so the natural frequency of the joists does not coincide with other building elements or rooms [3]. In many of the papers written on the subject of acoustics in wooden buildings it has been suggested that the measured frequency range of impact noise needs to be extended in the lower frequency end. In Sweden it is already standard practice to measure impact sound down to 50 Hz [15], but for wooden buildings it might be of interest to measure all the way down to 20 Hz [14]. It was shown in the studied papers that doing this would better correlate the measured results to the perceived sound experienced by the occupants.

Although, it should not be forgotten that using wood as building material also have some acoustical benefits due to its material characteristics. The wooden material have sound absorptive properties which affect the acoustical parameters of a room [16]. The reverberation time is one example of such a parameter and it can be reduced in a room with visible wooden surfaces. A wooden construction usually also have high damping at high frequencies [12] which can reduce problems with structure borne noise. When it comes to airborne sound, the wooden construction

can perform equally well as the heavyweight construction if double walls are used [8].

2.2.2 Concrete Buildings

Building multi-storey constructions in concrete have been a possibility since the development of reinforced concrete during the second half of the 19th century [17]. Since then a lot of developments have been made within the concrete industry where new technology made it possible, both technically and economically, to produce concrete with suitable properties for tall buildings [17]. Due to its strength, durability, fire resistance, sound insulation, and versatility, concrete has been preferred for multi-storey buildings [18]. Therefore, the majority of office buildings nowadays are heavyweight constructions made of concrete.

2.2.2.1 Concrete as Building Material

Concrete is currently the most widely used building material in general in the construction industry and has been for hundreds of years [19]. The composite material, consisting mainly of cement, water, and aggregate, creates a stiff, heavy, and robust construction material when mixed together [20].

When it comes to environmental factors, the concrete sector is a significant source of greenhouse gases that contribute to global warming [19]. When cement is burned a large amount of carbon dioxide is released which impacts the environment negatively. During demolition the concrete constructions can be reused and brought back to the manufacturing chain, but it can never replace the rock that was broken in order to make the cement [21]. To prevent climate change, it is essential to design buildings that have a lower environmental effect, such as wooden ones [19].

2.2.2.2 Acoustics in Concrete

When regarding acoustic properties, heavyweight buildings such as concrete structures provide a predictable sound environment [8]. The sound insulation as well as the sound levels within a concrete construction can be dimensioned with great accuracy using calculation programs [22]. Thereby, the use of concrete is the safest alternative when high sound requirements are demanded [23]. The material is not sensitive to small deviations during the construction, but a critical aspect is to ensure air tightness and correct mounting between building elements [20]. Small cracks and air gaps can impact the noise reduction and create a poor sound environment, but when mounted properly concrete structures effectively isolate noise even at low frequencies [20].

Concrete constructions provide satisfactory conditions for speech communication since the heavy material reduces background noise from adjacent spaces and installations [20]. However, both impact- and structure borne noise propagates far in concrete [24]. To achieve satisfactory sound insulation, both vertically and horizontally, floor coverings must be considered [20]. Floor coverings that dampens

impact noise are usually installed to prevent this problem. If the floor coverings is constructed poorly resonances might appear and this reduces the airborne noise insulation [24]. Additionally, insulation such as thin boards can be mounted on walls, ceilings, and floors to improve the noise insulation at high frequencies, since the material does not do this on its own [20].

At the low frequency range a large difference between lightweight- and heavyweight constructions can be found for the impact noise level, in some cases up to 20 dB higher for the lightweight buildings [23]. Complaints about impact noises are thereby more frequent in wooden buildings [23], and due to that the sound environment in a heavyweight building can in many cases be perceived as better. The main reason for this is that concrete is both heavier and stiffer, a combination which leads to favorable conditions for acoustic comfort [25].

2.3 Survey Methods and Statistics

There are many different ways of conducting a survey, and it is therefore important to study the theory of the survey method intended to be used. In this section the background theory of a questionnaire survey is presented, along with some basic statistics that can be used to analyse the outcome of the questionnaire.

2.3.1 Survey Methods

A survey method is a technique used for gathering data from a predetermined group of people by asking questions [26]. There are several types of survey methods, such as interviews, questionnaire surveys, or observations. In this chapter only theory about questionnaire surveys is presented since that is the method used for the thesis.

2.3.1.1 Questionnaire Survey

A questionnaire survey is a specific research method used for gathering statistical data about a populations characteristics, beliefs, or behavior by a structured set of questions [27]. Since a survey can be administrated through different media, such as by mail, over the telephone, or through the internet, the specific method will be able to gather information from a broad group of selected respondents [28]. A digital questionnaire survey is for example economical, fast, and easy. The digital survey is often distributed by email where the respondent only needs to press a button to answer the questions. At the same time, the data is being processed which makes it easier for statistical analysis later on [29]. A questionnaire survey could also be distributed on paper with mail and be completed by hand or online [27]. Generally, it is important to protect the privacy of the respondents and ensure that all information is confidential [27].

2.3.1.2 Designing a Questionnaire

When designing a questionnaire it can be in the form of a cross-sectional survey design. This specific design looks at data at a single point in time with respondents that are selected based on particular variables of interest [27]. Another design which can be used is longitudinal survey designs. This form evaluates multiple measures over an extended period to detect trends and changes [27].

The structure of the questions within a survey can be divided into four different categories depending on the research topic. Questions can either treat attributes and properties, behavior and habits, opinions and values, or knowledge [29]. The question and answers can be constructed in several different ways. For example, the questions can be constructed in either a closed or open-ended format [29]. Closed questions contain several answer options that the respondent should choose between, while open-ended questions require the respondent to state an answer in their own words [27]. The answer options can as well be formulated in different ways. The answer options could be fixed, which means that the answer alternatives already are given and that the options are limited [29]. When asking questions about the respondents opinions it is preferred to use rating scales. The scale could either be uniform or unequal. When using a uniform scale the respondent will not be able to choose a neutral answer and must thereby take a stand on the issue of matter. With an unequal scale, the respondent will be able to choose a neutral answer, the value in the middle, and thereby does not need to take a stand on the matter [29]. The unequal scale can for example be rated on a scale from 0 to 10 [30]. Another way to measure opinions is to use a Likert scale where the respondent often is given a statement and needs to decide if they agree or not [29].

To achieve a high response rate the number of questions should be kept short enough to fit within one page, this is for the ease of the respondents [30]. When there are too many questions, there is a higher chance of exhausting the respondents, which would raise the likelihood of random replies and lower the surveys reliability [31]. The survey should have a clear structure, with questions positioned in a natural context with headings that explains the content of the question [31]. The purpose of the survey as well as the chosen respondent group should be explained to the respondent in a cover letter. The letter should provide information about the questionnaire survey, how to participate, how confidentially will be handled, and how to get in touch with the authors of the survey [32]. Regarding the question sequence, it is recommended to start the survey with something easy, enjoyable, and non-controversial which makes the respondent interested in answering. The most important and demanding questions should be placed in the middle. Questions that might be perceived as easy, boring, or sensitive, such as personal information, should be asked last [29].

2.3.1.3 Conducting a Pilot Study

It is crucial to create questions that are simple, understandable, and straightforward [33]. The respondent needs to be able to understand both questions and answers without effort but as well feel respected. Thereby it becomes important to formulate the questions correctly [29]. By reviewing previous studies within the area of interest and reusing questions the validity of the survey can be increased. This is since the quality and design of the questions already have been examined and verified [32]. However, a pilot study can also be performed to control the quality of the produced questionnaire. A pilot study is a test examination carried out before the actual survey to determine whether respondents perceive questions and answer options similar to the author of the questionnaire. In this way, the surveys validity can be evaluated. It is common practice to conduct a pilot study by asking two smaller groups of participants to respond and provide feedback [32].

2.3.2 Statistics

When conducting surveys it is common to use statistics to interpret the results. To assume a certain accuracy of the statistical results, the response rate of the survey should be 70% or above [30]. Among the most basic statistical analyses to perform on the results are to calculate the average value, standard deviation and confidence interval. The standard deviation, σ , show how much the collected answers on an average deviates from the average value for each question investigated. It can be calculated using equation 2.1, where x is the observation value, \bar{x} is the average value and n is the number of observations.

$$\sigma = \sqrt{\frac{\sum(x - \bar{x})^2}{n}} \quad (2.1)$$

The confidence interval is the range in which the true average value of the whole population will lie with a certain probability [34]. It is used when analysing the results of a survey which has investigated only a sample of the entire population, since the average of this sample will deviate slightly from the average of the whole population. The most commonly used probabilities for the confidence interval is 95% and 99%. The confidence interval, CI , can be calculated using equation 2.2, where \bar{x} is the average value of the sample, z is a value based on what probability that is used (for 95% it is 1.96 and for 99% it is 2.58), σ is the standard deviation and n is the sample size.

$$CI = \bar{x} \pm z \cdot \frac{\sigma}{\sqrt{n}} \quad (2.2)$$

If the results are being compared, an analysis can be made to see if they have a real difference or if the difference is random [35]. This can be made by looking at the confidence intervals and see if they overlap or not. If they do not, then there is a statistical significant difference between the results. If the confidence intervals overlap it can not be sure whether the difference between the compared results is real,

or if it is just random or caused by uncertainties in the survey. Further statistical computations are therefore needed to be able to say anything with certainty.

2.4 Acoustics and Regulations in Offices

Since the majority of people spend a lot of time at the office it becomes important to regard the acoustic environment at the workspace. In this section, theory about acoustics in offices will be presented, followed by regulations and requirements regarding sound levels within the office environment.

2.4.1 Acoustics in Offices

New ways of working contribute to the constant development of workspaces. Office layouts used to be created with functionality of the work environment from an employee perspective in mind, but these days the emphasis is on cooperation, creativity, and innovation. To achieve this a favorable design choice is the open plan office layout [36]. However, when open office spaces are introduced the employees will encounter drawbacks when working, such as loss of productivity as well as noise problems [36].

2.4.1.1 Office Noise Effect on Cognitive Performance

Compared to a private office the acoustic environment in an open plan office is perceived as less satisfactory [37]. Employees are more likely to be disturbed when working in a multi-person office, especially when conducting tasks that require concentration [3]. A study shows that employees working in open offices perceive that they need to make significantly more cognitive efforts, as well as experience more stress-related symptoms compared to people working in private offices [37]. An Australian study also indicates the same result where increased stress and lower mood were found for employees in an open plan office compared to a private office [38]. Office noise is also proven to have a negative effect on cognitive performance, such as performing a task that includes mental arithmetic, learning of words, and understanding or recalling text [37]. Furthermore, it appears that office noise can impact employees physical and mental health [37].

2.4.1.2 Different Noise Sources in the Office

In offices, noise can be caused by various sources such as phones ringing, colleagues talking on the phone and with each other, sounds from people working, office equipment, ventilation or air-conditioning systems as well as noise from outside the building [37]. Office noise can be bothersome, cause annoyance and disrupt the workers concentration. Background speech is reported to be the most bothersome noise source in the office environment, while telephones ringing give the most disruption

to concentration [37]. The background noise should not be too low or too high. If the background noise is too low the speech confidentiality can be lost since the office environment is too quiet [3]. However, if it is too high the office environment can be perceived as loud, and some masking of the speech can appear [3]. In the ideal office space, both good speech communication and good speech privacy co-exists within the same space [39]. Another study found that the three most annoying sound sources in the office environment were conversations between colleagues, ringing phones, and noise from machines (e.g. printers) [40]. Traffic noise is reported to give the least disruption to the workers concentration [39]. However, employees who perform with low productivity can be more affected by background noise, closing doors, noise from human activity as well as other non-specified noises [40]. Another thing to regard is that our tolerance for noise is different. Some employees are more sensitive to noise and need a quiet space to retain concentration while some need a lively acoustic environment [41]. Thereby it becomes important to create working environments that fit everyone, for example by adding focus rooms.

2.4.1.3 How Office Noise is Perceived

It is noted that noise sources that can be considered as manageable and functional are perceived as less disturbing than sources considered unmanageable and non-essential [37]. For example, a ventilation system that generates a continuous noise can be perceived as less disturbing compared to a source with variable noise. Generally, it is easier to get used to a constant noise than a variable one since the brain easier filters out these kinds of sounds [37]. As mentioned before colleagues talking is considered one of the most bothersome sound sources within the office environment. This is because our brain reacts to human speech and believe that we need to listen to the information [41].

2.4.1.4 How to Improve the Acoustic Environment in the Office

Disturbing noise within the office environment can not be completely avoided regardless of how the office space is designed, but sounds throughout the workspace should be monitored regularly to ensure proper working conditions for the employees [3]. It is important to regard room acoustics, sound propagation, and placement of installations when designing office spaces, and these things require careful planning [3]. If the acoustic environment within the office area is not sufficient, different measurements can be taken to improve the sound environment. This can for example be to add boundaries between different working groups, to add sound absorbers with high absorption coefficients, or to use high and dense screens [3]. Another thing to regard is that the impact noise can be perceived as disturbing when insufficient floor constructions are used. It is thereby important to provide flooring that limits impact noise [3].

2.4.1.5 Too Quiet Office Environments

Another problem is that a lot of today's open plan offices are too quiet. Nowadays, when designing offices, a lot of emphasis is put into creating heavily dampened work environments where concentration is in focus. However, this can backfire since the smallest noise becomes audible when the space is too quiet. A way to solve this is by adding background noise, such as birdsong, rustling leaves, or whistling wind. By adding noise masking of sound is created and employees will be less disturbed by other sounds around them [41].

2.4.2 Regulations and Requirements for Acoustics in Offices

The requirements regarding noise levels in an office environment are described in the Swedish standard SS 25268:2007+T1:2017 [42]. Arbetsmiljöverket presents some indicative values for different working conditions [43]. The indicated values suggest a relatively low noise level of 40 dB(A) for working conditions where high-concentration tasks or discussions are a regular component of the workday. However, the value does not include employee or corporate activities that contribute to the noise [43]. Therefore the sound insulation requirements may need to be adapted to fit the demands for cooperation or confidentiality within the office [3]. For tasks requiring concentration or confidentiality, there must be room for individual work and conversations directly connected to the open workspace [42].

2.4.2.1 Swedish Standards Sound Classifications

The Swedish standard SS 25268:2007+T1:2017 [42] specifies sound classifications of spaces in buildings, where rooms for office work are included. According to the standard, rooms in buildings must be planned such that noise from example installations, adjacent rooms, and traffic noise is dampened to prevent worker disruption and preserve the appropriate level of privacy protection. When designing a working environment it must adhere to certain criteria, one of which being the Swedish Standards sound classifications, defined as A, B, C, and D. The Swedish Housing Authorities defines sound class C as the lowest level, what is thought to be necessary for an acceptable sound environment, and class D as an exception [44]. As a result, sound class A is considered the best. The different classes set requirements for the sound levels according to various parameters such as airborne noise, impact noise, installation noise, traffic noise, and reverberation time [3]. According to SS 25268 the minimum requirement for rooms used for office work is sound class C, but the developer could also choose to construct offices with a better sound environment, such as sound class A or B [44]. To achieve sound class A or B workplaces must be shielded from other areas with high passenger traffic or noise-generating sources. The design of the office space should as well be adapted to the usage of the spaces [42].

2.4.2.2 Apparent Sound Reduction Index

SS 25268:2007+T1:2017 [42] gives values for the sound insulation between offices and areas within the same workplace, in other words how much sound that is reduced from one room to another. The standard for example states a requirement for the apparent sound reduction index, R'_w , between office rooms for one person and other spaces which is 35 dB [42]. This is due to the certain amount of privacy which is expected in a single room with the door closed. The requirements for the door is practically adapted so sound classified doors, sliding doors as well as glass sections can be used facing the corridors [3]. Between spaces that are united by common open areas, e.g. different workplaces within an office landscape, requirements for reduction numbers do not apply [42]. However, from another space into areas with demands on moderate privacy or seclusion, such as meeting rooms, the standard states that the R'_w should be at least 44 dB [42]. Yet, for areas requiring high demands of privacy the value for R'_w should be at least 48 dB [42].

2.4.2.3 Highest Weighted Standardized Levels for Impact Noise

Concerning the impact noise SS 25268:2007+T1:2017 [42] gives values for the highest weighted standardized level, $L'_{nT,w}$, recommended in offices. When considering sound class C the standard states requirements for both larger conference rooms as well as sound levels to and from other departments. The standard gives sound levels for both low and high impact loads. Regarding conference rooms the $L'_{nT,w}$ is given as 60 dB for low loads and 56 dB for high loads [42]. The $L'_{nT,w}$ from and to other departments is given as 68 dB in both cases [42]. For a low load of impact noise the standard have no requirements for neither office rooms nor smaller meeting rooms or conference rooms. However for a high load of impact noise the standard gives values for both spaces. The $L'_{nT,w}$ in office rooms with high load is in that case 68 dB and in meeting or conference rooms 64 dB [42].

2.4.2.4 Reverberation Time and Installation Noise

SS 25268:2007+T1:2017 [42] gives indicative values for both the longest reverberation time in an office room, T_{20} (written $T_{20,125Hz}$ if measured down to 125 Hz), as well as the highest A-weighted, $L_{A,eq}$, and C-weighted, $L_{C,eq}$, equivalent sound level from installations. The requirements for the reverberation time ranges from 0.4 to 0.8 seconds depending on the function of the space. For $L_{A,eq}$ the equivalent sound level ranges from 30 to 40 dB depending on space while the $L_{C,eq}$ ranges from 50 to 60 dB [42]. In areas where vocal communication is essential it is important that the installations do not produce disturbing background noise. For example can noise from ventilation devices, which exceeds the indicative values for the equivalent sound level in the standard, be perceived as disturbing for the workers [3].

3

Methods

The method chapter describes the methods used to investigate the subject and obtain the results. The chapter gives an overview of the offices participating in the study, the creation and distribution of the questionnaire, the analysis process of collected available measurement data and an explanation of the study visit.

3.1 Selection of Offices

In this section the eight offices involved in the study are described. In total there are four wooden offices, three concrete offices and one office with both concrete and wooden parts. All offices are located in Sweden and are relatively newly built. The selection of offices for the study was made deliberately and not randomized, and the main reason for choosing the buildings was the type of construction and the period they were built in.

3.1.1 Nodi, Nya Hovås

Nodi is located in Nya Hovås, approximately 20 minutes outside of Gothenburg city. The building is designed by White Arkitekter for Next Step Group, and the construction entrepreneur was BRA-bygg [45]. The building started in 2019 and in 2021 the first tenants moved in [46]. The building hosts both shops at the ground floor and offices at the floors above. At the top floor there is also a common outdoor terrace for the tenants to use [46]. The five storey building is constructed primarily in glulam wood (wooden slats glued together to form a thicker piece of wood), with a stairwell and basement made from concrete [45]. One of the key features with the building is the increasing size of the floors at each level [47]. The choice of a wooden construction is partly due to the low impact the material has on climate while it also helps to create a pleasant indoor environment [47]. The design of the building is meant to enhance the feeling of being in a wooden building and this is done for example by having a lot of visible wood elements both inside and outside [46]. Using a lot of glass in the facade also show of the wooden structure [46]. The office parts of the building is a mixture of meeting spaces and some smaller working rooms, but the majority of the spaces are open plan offices. The most tenants rents a quarter of the floor, but it is also possible to rent a whole floor [46].



Figure 3.1: The wooden office building Nodi, Nya Hovås. Left picture shows the outside of the building, right picture shows a part of the inside.

3.1.2 Magasin X, Uppsala

Magasin X in Uppsala is Sweden's biggest office building constructed in wood [48]. The construction started in September 2019 and the tenants started to move in two years later in October 2021 [48]. It is White Arkitekter that have designed the building for Vasakronan, and general contractor was in cooperation with NCC Sverige AB [48]. The building is made out of glulam wood [49] and has joists of cross laminated timber (CLT) [50]. It has a pillar structure that stretches vertically through the whole building [50], and visible X-shaped wind crosses [49]. The main focus of the project was sustainability and the framework is completely constructed in wood [48], as well as the stairwell and elevator shaft [49]. Choosing wood as material gave opportunities for a better indoor environment and fewer transports during the building of the frame, while it at the same time gives the building a smaller carbon footprint since the material is renewable [48]. Magasin X is certified with LEED Platinum and works with sustainable solutions in several different ways [48]. The building is seven stories high and contains an area of total 16 600 m² [49]. One of the challenges with the build was the acoustics due to the lightweight material [48]. The building hosts several companies as tenants, as well as a co-working area and a restaurant [48]. The layout on each floor has been adapted depending on the tenants needs [50].



Figure 3.2: The wooden office building Magasin X, Uppsala. Left picture shows the outside of the building, right picture shows a part of the inside. *Reproduced with permission from Jonas Wahlström, Vasakronan.*

3.1.3 A Working Lab (AWL), Gothenburg

A Working Lab (AWL) is located at Chalmers campus Johanneberg in Gothenburg. The building is designed by Tengbom Arkitekter for Akademiska Hus and the construction entrepreneur was ByggDialog [51]. The 12000 m² office building was produced between 2016 to 2019 and has over 400 workplaces in a co-working environment [51]. The office building is based on a national concept by Akademiska Hus where the goal is to develop learning environments to make it possible for more flexible meetings between students, researchers, and businesses [52]. AWL works on a co-working principle where companies, businesses, and people can rent a spot in the building and use it for their specific needs [52]. The office layout is designed with multi-functional and adaptable spaces as well as an open floor plan, which creates possibilities for flexible workspaces [53]. The five-storey building is constructed using a frame with elements of massive wood [54]. The stairwells in concrete acts as the stabilizing unit since the material is both heavy and able to transfer large loads [54]. Steel beams are used to give the building height whilst CLT is used for the frame of the building as well as the joists [54]. The massive wood in the frame was chosen to minimize the building's climate impact, which is assumed to be 20% lower compared to if a traditional concrete frame would have been used [51]. The main focus when constructing the building was to create a climate-smart, resource-efficient building with a low environmental impact. Thereby AWL is nowadays certified according to Miljöbyggnad Gold [53]. The building was designed using an innovation-process where different projects, focusing on climate and sustainability, laid the foundation for the work. For example, a research project regarding good acoustics in wooden joists was conducted [55].



Figure 3.3: The wooden office building A Working Lab (AWL), Gothenburg. Left picture shows the outside of the building, right picture shows a part of the inside.

3.1.4 Trikåfabriken, Stockholm

Trikåfabriken is a reconstruction project located in Hammarby Sjöstad, Stockholm. The old knitwear factory from 1929 has been turned into an office with an extended wooden frame of five floors, placed on top of the original building [56]. The building was designed by Tengbom Arkitekter for Faberge and the general contractor was Arcona [57]. The project was developed between 2014 to 2019 and is an example of how the past and the present can be connected through architecture [56]. The office building has an industrial character where the original building is made out of brick and the extension is made out of wood, corten sheet metal, and glass [56]. The goal with the facade was to recreate the brick in a new way by covering the facade in sheet metal [56]. The extended wooden construction consists of columns and beams in glulam timber as well as joists in CLT [58]. All elements of wood are exposed on the inside as well as visible from the outside [56]. Since the building elements in wood have a low weight in relation to their load-bearing capabilities it was possible to build on top of the old factory without impairing it [59]. The wooden frame was also preferred for sustainable reasons and nowadays the building is certified according to BREEAM Very Good [56]. The office layout is designed with an open floor plan as well as co-working spaces to promote a more activity-based style of working [56]. The building hosts both a state agency as well as an authority.



Figure 3.4: The wooden office building Triåkfabriken, Stockholm. Left picture shows the outside of the building, right picture shows a part of the inside. *Reproduced with permission from Magnus Smedmark, Fabege.*

3.1.5 Johanneberg Science Park (JSP 1), Gothenburg

Johanneberg Science Park (JSP 1) is located at Chalmers campus Johanneberg in Gothenburg and is Sweden’s leading collaborative operation within urban development [60]. The project was developed between 2010 to 2015 and was designed by White Arkitekter for Chalmersfastigheter [61]. The five-storey concrete building was constructed by Skanska and consists of two buildings with a glass facade connected by a bridge [61]. The two office building hosts both open plan offices in a co-working environment as well as a restaurant and coffee shop [62].

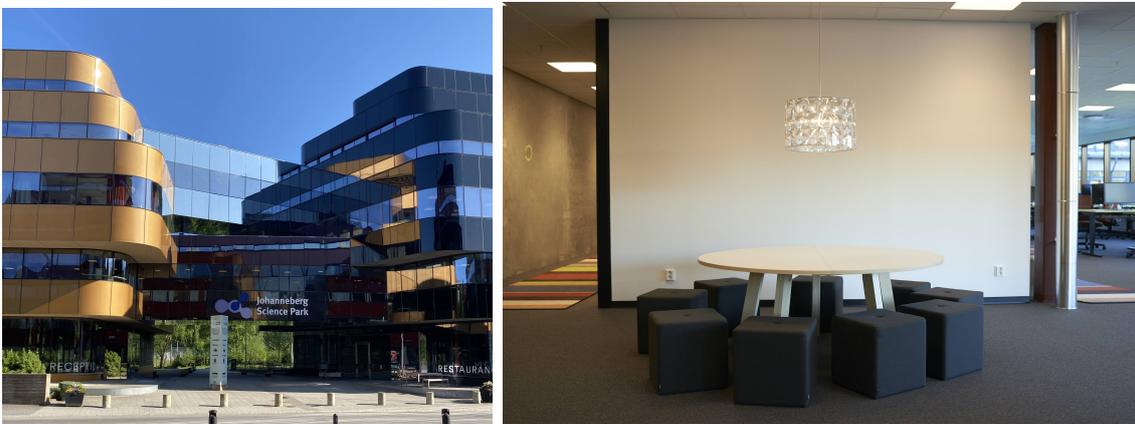


Figure 3.5: The concrete office building Johanneberg Science Park (JSP 1), Gothenburg. Left picture shows the outside of the building, right picture shows a part of the inside. *Picture of interior taken by Mats Bengtsson and reproduced with permission from Evelina Nikola, Chalmersfastigheter.*

3.1.6 AFRY (ÅF-huset), Gothenburg

ÅF-huset is located close to the E6 motorway in Kallebäck, Gothenburg. The building was developed between 2011 to 2014 and is nowadays a 16-storey office made of concrete with a double-glazed facade [63]. The building was designed by Arkitek-

tbyrå Design for Skanska who acted both as the developer and prime contractor [64]. The office layout is mainly open plan and one of the tenants is a consulting firm.



Figure 3.6: The concrete office building of AFRY (ÅF-huset), Gothenburg. Left picture shows the outside of the building, right picture shows a part of the inside.

3.1.7 AFRY (ÅF-huset) in Solna, Stockholm

AFRYs headquarter is located in Solna, Stockholm close to the E4 motorway. The building was projected between 2006 to 2008 by Skanska who acted both as the developer and prime contractor [65]. The architect behind the project is Strategisk Arkitektur who designed the building in collaboration with Solna stad, Skanska as well as the tenant AFRY [65]. The 10-storey building has a structure made of concrete and a glazed facade [66]. The office layout is mainly open plan as well as activity-based [66], and the tenant is a consulting firm.



Figure 3.7: The concrete office building of AFRY (ÅF-huset) in Solna, Stockholm. Left picture shows the outside of the building, right picture shows a part of the inside. *Reproduced with permission from Samuel Tuvenlund, Efterklang Part of AFRY.*

3.1.8 Trafikverkets Headquarters, Borlänge

The headquarters of Trafikverket is situated in Borlänge and consist of several older concrete buildings connected by a newly built elliptic shape in cross laminated timber [67]. The rebuild of the office and addition of the wooden part took place during the period 2019 to 2022 when Trafikverket moved back in [68]. The architecture firm behind the project is Krook & Tjäder on request from the property owners Diös [67], and the general contractor was ByggPartner [69]. An important focus point has been on reuse and recycling of the old premises [67]. Using CLT in the newly built ellipse is done partly from a sustainability perspective to reduce the environmental footprint of the building, and the old buildings are Breeam In Use, very good, certified [67]. In total, the building area is 31 000 m² and of those are 2000 m² newly built [69]. The office layout is activity-based [68]. In the new wooden part of the building there are areas for both work and recreation for the workers to use [67].



Figure 3.8: The concrete and wooden office buildings of Trafikverkets Headquarters, Borlänge. Left picture shows the outside of the building, right picture shows a part of the inside. *Reproduced with permission from Trafikverket.*

3.2 Survey Method

In this section it is described how the survey study was conducted, starting with the designing of the questionnaire, followed by the pilot study, how to contact the offices and the process of collecting the answers.

3.2.1 Questionnaire Design

The questionnaire design was based on the findings of the literature study. The content of the questions as well as the layout was partly inspired by the standard *Acoustic quality of open office space (ISO 22955:2021, IDT)* [70] and the *AkuLite Report 2 (SP report 2011:58)* [30]. It was also inspired by the results presented in

reports of previous studies (studied in the literature study) as well as the knowledge gathered on acoustics in wooden and concrete buildings. The books about survey methods assisted in creating the layout of the questionnaire. It was decided to create the questionnaire in the program Google Forms. The questions was categorised into different chapters to make it more clear to the respondent what was asked. The first chapter is *General information about your workstation at the office*, the second *Assessing the acoustic environment of your work area*, the third *Perception of the acoustic environment*, the fourth *Effects of the COVID-19 pandemic on workplace* and the last *General information about you*. The full questionnaire can be found in appendix A. The categories was decided with regards to the content of the questions and the areas desired to investigate using the survey study. Main focus of the questionnaire content was to collect results of how people in wooden and concrete offices experience the acoustic environment in their work area. It also gathered information about their work situation, both of these things are hard to collect information about in other ways.

3.2.1.1 Types of Questions

The majority of the questions in the questionnaire was chosen to be of the type that uses a 0 to 10 scale for assessing the level of disturbance, how frequent the disturbance is experienced and how the respondent perceive the acoustic environment at their workstation. It was decided to us a rating scale for these questions, since the questions asks for the respondents opinion. The scale was chosen based on the suggested questionnaire in the AkuLite report 2 [30]. The 11-grade scale allowed for the respondent to choose a neutral option in the middle, 5. Figure 3.9 show an example from the chapter *Assessing the acoustic environment of your work area* in the questionnaire. The structure of this chapter followed the example; first it asked about the disturbance and then about how frequent the disturbance is experienced.

12. In general, are you disturbed by sounds from machines in the office (e.g. printer, computers, phones ringing)?

0 1 2 3 4 5 6 7 8 9 10

Not at all Totally

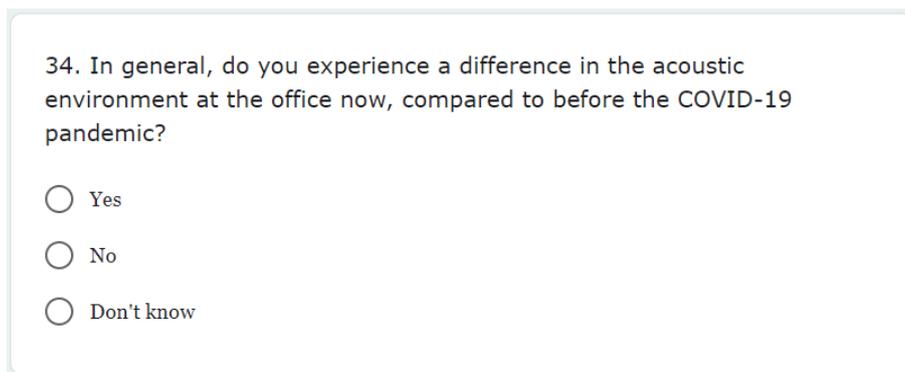
13. How often do you feel disturbed by sounds from machines in the office (e.g. printer, computers, phones ringing)?

0 1 2 3 4 5 6 7 8 9 10

Never Constantly

Figure 3.9: Example of a scale question from the questionnaire.

Another big category of questions in the questionnaire was the multiple choice questions. This type of questions was used when the respondent was asked to pick one answer from a list of a few given options. It was decided to give set options to avoid a huge variety of answers for these questions. Some of them had an open-end option to chose if the given alternatives did not correspond to the respondents experience or situation. An example of this question type from the questionnaire is shown in figure 3.10.



34. In general, do you experience a difference in the acoustic environment at the office now, compared to before the COVID-19 pandemic?

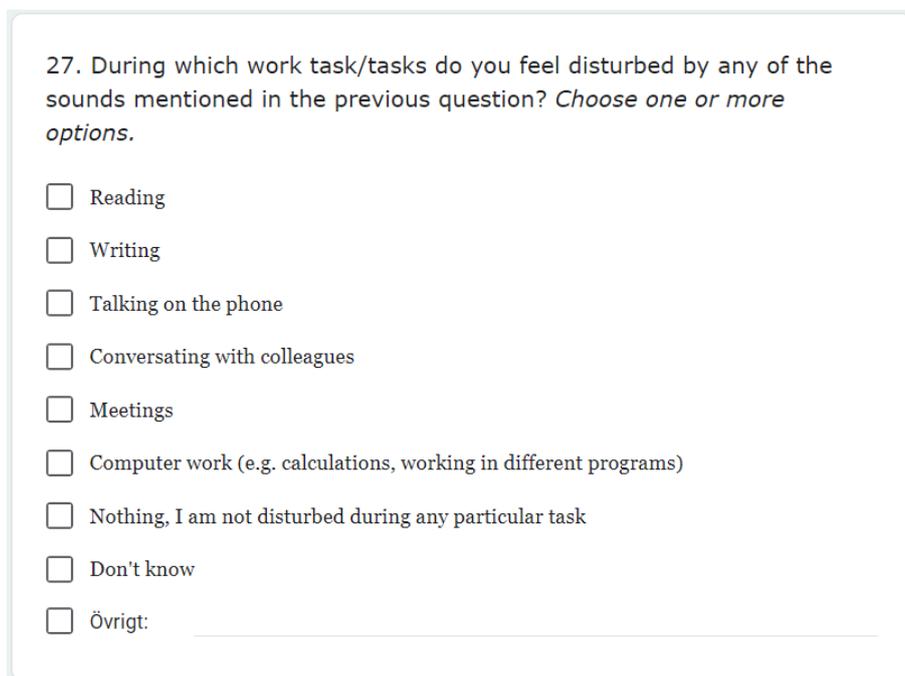
Yes

No

Don't know

Figure 3.10: Example of a multiple choice question from the questionnaire.

Two questions in the questionnaire was chosen to be multiple choice questions with a multiple select format to get an overview but reduce the variety of the response. In these questions the respondent was able to mark several options out of a set of given answers. Figure 3.11 show an example of one of the questions from the questionnaire.



27. During which work task/tasks do you feel disturbed by any of the sounds mentioned in the previous question? *Choose one or more options.*

Reading

Writing

Talking on the phone

Conversating with colleagues

Meetings

Computer work (e.g. calculations, working in different programs)

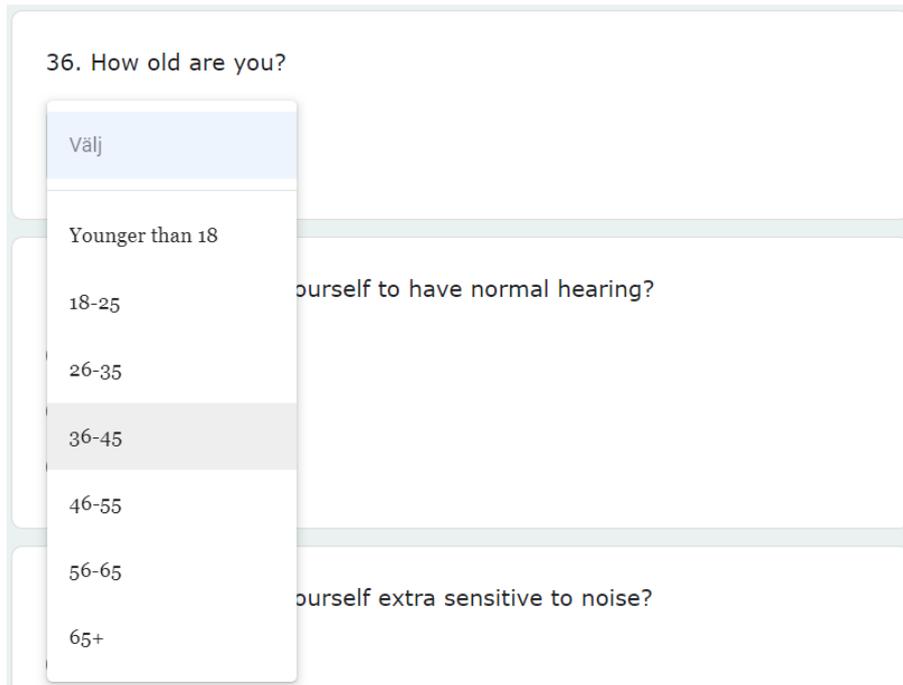
Nothing, I am not disturbed during any particular task

Don't know

Övrigt: _____

Figure 3.11: Example of a multiple choice question with a multi select format from the questionnaire.

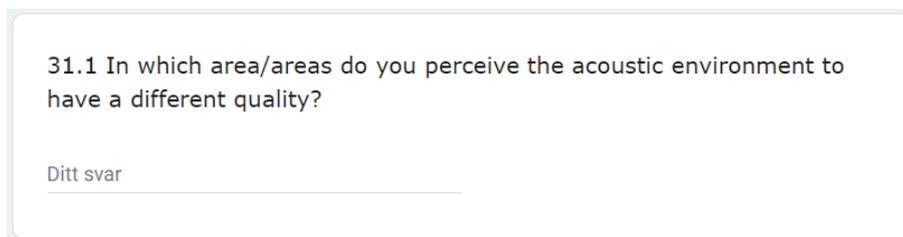
For some of the questions it was found most appropriate to use an interval option for the answer, mainly for the questions asking about years, to group the responses. The options was put in a drop down menu to take up less space, and at the same time allow for many different intervals. In figure 3.12 an example of an interval question in the questionnaire is shown, with the drop down menu opened to display the answer options.



The image shows a screenshot of a questionnaire interface. At the top, question 36 is displayed: "36. How old are you?". Below the question is a dropdown menu that is currently open, showing a list of age intervals. The menu starts with a header "Välj" (Select) in a light blue box. The options listed are: "Younger than 18", "18-25", "26-35", "36-45" (which is highlighted with a grey background), "46-55", "56-65", and "65+". To the right of the dropdown menu, parts of other questions are visible: "yourself to have normal hearing?" and "yourself extra sensitive to noise?".

Figure 3.12: Example of an interval question from the questionnaire.

Finally, some of the questions in the questionnaire was of the type with open-end where the respondents was asked to write an answer in their own words. These were used when it was unknown what the respondents might want to answer, because the responses could differ a lot. It was stated in the beginning of the questionnaire that the respondent could chose to answer the open-end questions in either English or Swedish. The open-end questions only required short answers. Figure 3.13 show an example of an open-end question from the questionnaire.



The image shows a screenshot of a questionnaire question. The question is numbered 31.1 and reads: "31.1 In which area/areas do you perceive the acoustic environment to have a different quality?". Below the question is a text input field with the placeholder text "Ditt svar" (Your answer) and a horizontal line for writing.

Figure 3.13: Example of an open-end question from the questionnaire.

3.2.2 Pilot Study

The pilot study was conducted as a part of refining the content and layout of the questionnaire. The purpose was to collect feedback on how the questionnaire was perceived by a respondent, to make it more user-friendly. The study took place in two turns, one to get reactions on the primary version of the questionnaire and one to understand how well the final version would work. The groups were not randomly selected. The people chosen to participate in the pilot study were people we know, and therefore knew would not be part of the real survey. When choosing the pilot study groups, six people were asked to participate in each group, which of half identifies as female and half as male. A spread of age groups was also tried to be achieved, where half of the participants of each group was in the younger age intervals and half in the older age intervals.

The participants of the pilot study was first contacted and asked to be part of testing the questionnaire. Once they had approved, an email with some additional information about the thesis work, why the pilot study was conducted and some information of how to go through with testing was sent out to one group at the time. The questionnaire that was sent out included all parts that would be in the real survey, but also an additional part in Swedish where the respondents was given the opportunity to leave some feedback. The answers from the pilot study was analysed with focus on whether or not the participants had responded to the questions in a way that seemed like they had understand the content and formulation of them. The feedback part was also studied to understand how the pilot groups had perceived the questionnaire. Using this information, the questionnaire was refined to be able to collect a bigger amount of useful answers in the real survey.

3.2.3 Contact with Offices

Before sending out the questionnaire to the offices selected to participate in the study, contact had to be made. First, the property owners were contacted via email. In the email it was explained what the thesis work is about and why we wished to conduct a study in their building. Permission to send out the questionnaire to the companies with offices in their building was asked for. It was explained that the study was made with a positive viewpoint on wooden buildings.

Following the email conversations with the property owners, contact could be made with the companies in the buildings approved to be part of the study. It was again explained what the thesis work is about and why we wished for the workers in their office to be part of the study. It was also asked if the contact person could distribute the link of the questionnaire to the people in the office. It was therefore not known how many people in each office that was asked to participate, which made it impossible to know the response rate. Before Easter, a request to send out a reminder was made to the wooden offices participating in the study, with intention to increase the response rate. Contact with the concrete offices was made after Easter.

3.2.4 Compilation and Analysis of the Questionnaire

Some weeks after the questionnaires had been distributed they were closed and could no longer be answered. The respondents had been informed about the closing date both at the beginning and end of the questionnaire. The answers were exported from Google Forms to Google Spreadsheet, and from there downloaded as an Excel sheet. All of the responses for all questions was displayed on the same sheet, and to get a better overview of the responses the data was sorted based on which office the respondent was from. The data for each office was both placed in their own sheet, as well as in a sorted list displaying all answers for each office type. In this way it was possible to make comparisons both within and between office types.

For all offices, as well as the lists with office types, the answer percentage for each question was calculated by counting the number of a certain answer option and divide it by the total number of responses. This was done for every question and meant that the answers could be compared between offices even though the number of respondents differed. Based on these percentages graphs was created showing the results. It was chosen to display the answer percentages using pie charts and bar charts. For the wooden offices, a graph was created for each question with exception for the open-end questions. Graphs were also created showing the answers to questions number 6 to 31 in the questionnaire, which can be seen in appendix A, for all three office types at the same time to allow easier comparisons.

Finally, the mean values, standard deviations and confidence intervals was calculated using the built in functions in Excel for question 6 to 25 and 28 to 30 for all three office types. Bar charts were created for these results as well.

3.3 Measurement Data

The second part of the method in this thesis was the collection and analysis of available measurement data for the investigated buildings. In this section it is described how the data was collected and how it was used for the thesis.

3.3.1 Collection of Measurement Reports

For all the investigated buildings, measurements had already been made for some of the most common parameters such as airborne sound insulation (R'_w), impact sound level ($L'_{n,Tw}$), reverberation time ($T_{20}(T_{20,125Hz})$) and installation noise ($L_{A,eq}/L_{C,eq}$). These measurements had been made by different consultancy firms at different points in time. The data was received in measurement reports and contained singular values for the different parameters (although not all reports contained values for all parameters investigated). The first step to collect the available data was to figure out which company had done the measurements for which building, and who to contact about it. For some of the buildings it was easy to find out by searching the internet, but for some, e.g. Trikkårbiken, it was harder and several people had to be contacted before figuring out who owned the data.

The measurement reports were then collected by emailing the company owning the report and explaining what the thesis work is about and why the data would be of use to it. It was also explained what type of data that was of interest to take part of. Permission to use the data in the thesis report was asked for as well. The amount of available data differed from office to office, and for AFRY in Solna, Stockholm, no measurement reports were available. For some of the offices, diagrams over the measured data in octave bands and third octave bands were received for certain parameters.

Following measurement reports was collected and used in the thesis:

- *PM NODI-Kontorshus och mötespunkt i Nya Hovås [71]*
- *Verifiering akustik - Rapport A Magasin X, Uppsala- Nybyggnad, kontor 757548 [72]*
- *A Working Lab Mätning av ljudisolering 724096 [73]*
- *A Working Lab Mätning av ljud från installationer 724096 [74]*
- *A Working Lab kontrollmätning av efterklangstid 724096 [75]*
- *724096 PM04 - A Working Lab Verifiering av ljudmiljö miljöbyggnad silver - sammanfattande PM [76]*
- *Trikåfabriken 9 Kontrollmätning av ljudisolering [77]*
- *Johanneberg Södra Etapp 1, Göteborg Kontroll av ljudisolering och installtionsbuller Ackrediterad mätning [78]*
- *Fältmätning av efterklangstid - ISO 3382-2:2008 (kurvblad) [79]*
- *Rapport Hus 13 Byggpartner AB, Trafikverket Borlänge kontor 778195 [80]*
- *Rapport X, Hus 14 & 15 Byggpartner AB, Trafikverket Borlänge kontor 778195 [81]*
- *Rapport Hus 16 Byggpartner AB, Trafikverket Borlänge kontor 778195 [82]*
- *Rapport Hus 17 Byggpartner AB, Trafikverket Borlänge kontor 778195 [83]*
- *Rapport Hus 25 Byggpartner AB, Trafikverket Borlänge kontor 778195 [84]*
- *Rapport Hus 34 Byggpartner AB, Trafikverket Borlänge kontor 778195 [85]*
- *Rapport C, Hus 14 Byggpartner AB, Trafikverket Borlänge kontor 778195 [86]*

3.3.2 Processing the Measurement Data

After collecting the available measurement reports the data was transferred from the reports to Excel. A sheet for each office type was created and the data for the offices was sorted into them based on which parameters that had been measured. For each parameter the data for every office was further sorted into subgroups based on the requirement. A characteristic value for the building was then found by calculating the average in each subgroup.

It was desired to be able to compare the offices and correlate the results found from the measurement data to the answers in the survey. Since the different offices and measurement parameters did not have the same sound class and therefore not the same requirements the calculated averages could not be compared directly. To allow

some sort of comparison, the difference between the requirement and the measured average was calculated for each subgroup.

3.4 Study Visit

One study visit was made during the ongoing thesis work. It was in the building Nodi in Nya Hovås and took place on the 4th of May after lunch. The property owners made an offer for the authors of this thesis to come and visit the building and have a look around.

The study visit started with a short and casual meeting in one of the meeting rooms in the property owners office area. During this conversation general questions, information and observations about the building and the acoustics were discussed. After the meeting the contact person gave a tour in the building, showing an empty office space undergoing adjustments for the next tenant, the stairwell and the outdoor space on the top floor.

4

Results

In this chapter the results of the thesis is presented in three parts; a presentation of the questionnaire results from the wooden offices, a comparison of the answers from all of the offices including a statistical comparison, and an analysis of the collected available measurement data. For the wooden offices, all answers from the questionnaire apart from the open-end questions are presented. Relevant answers are commented on in the text if they add additional information to the result. For the comparison it is questions 6 to 31 that is presented with graphs. Additional interesting answers are commented on in the text. The answers from the questionnaire are presented as answer percentages, to allow for comparison between offices with different amount of responses. Responses from Trafikverkets headquarters in Borlänge are analysed separately from the wooden and concrete constructions due to it being a combination of old concrete buildings and a new wooden construction. The results from the scale questions in the questionnaire are evaluated based on that 5 on the scale is neutral, and that answers below 5 therefore represent a disturbance at an acceptable level and above 5 a disturbance at an unacceptable level.

4.1 Questionnaire Results for Wooden Offices

The graphs that are shown in this chapter are presented as a compilation of the questionnaire answers from all of the wooden offices, and will thereby not show the result from each individual office. This is decided to do since the thesis investigates the acoustic environment in wooden offices as a whole group, compared to the acoustic environment in concrete offices as a whole group. However, if anything specific stands out in the answers from any of the individual offices it is commented on in the text.

The first group of questions concerns general information about the respondents workstation, and the results are presented in figure 4.1. In total 43 answers are received, out of which 47% is from A Working Lab (AWL). The least amount of answers received are from Nodi, from which only 4 answers was received. The distribution of answers can be seen in the top left graph in figure 4.1. By looking at the graph it is clear that Nodi is very underrepresented, and the response rate from Trikäfabriken is low as well. Out of the four wooden offices investigated, a clear majority of the respondent has workstations located in an open plan office layout, which can be seen in the top right graph. Few of the respondents have a workstation located in a private office room, and by looking at the individual answers it can be

4. Results

seen that these respondents work at either Nodi or AWL. From the written answers and comments throughout the questionnaire it can be understood that many of the people who answered "open plan office" sit in an activity-based office layout. The one answer in the option "other" specified that they sit in an activity-based office layout.

In question number 2 it was asked how many people are located in the same workspace. The results are shown in the middle to the left in figure 4.1. A third of the respondents answered "More than 40", but in general the answers are varying a lot for this question. By looking at the individual answers for question 2 it can be seen that Nodi generally have fewer people working in the same space, while Magasin X and Trikáfabriken usually have more people. For AWL the answers have a bigger spread. What can be seen though, is that very few of the respondents sit alone in their workspace which corresponds well to the answers of question number 1. The middle right graph shows that almost all of the respondents sit at another floor level than the top- or ground floor, which could be of importance to the answers regarding impact noise and noise from outside the office space.

The answers to question number 4 are all in the lower range, as seen in the bottom left graph in figure 4.1. This is an expected result since all the investigated buildings are newly built (none is older than five years). Question number 5 show the result that more than 80% has not changed the type of workstation in their current office. Of the answers saying "No/Other", it could be noticed from the written answers in the follow up question that the respondents has misunderstood what was asked. For example, several of the answers mentions activity-based office layout where they have to find a new place to sit every day. The result is shown to the bottom right in figure 4.1.

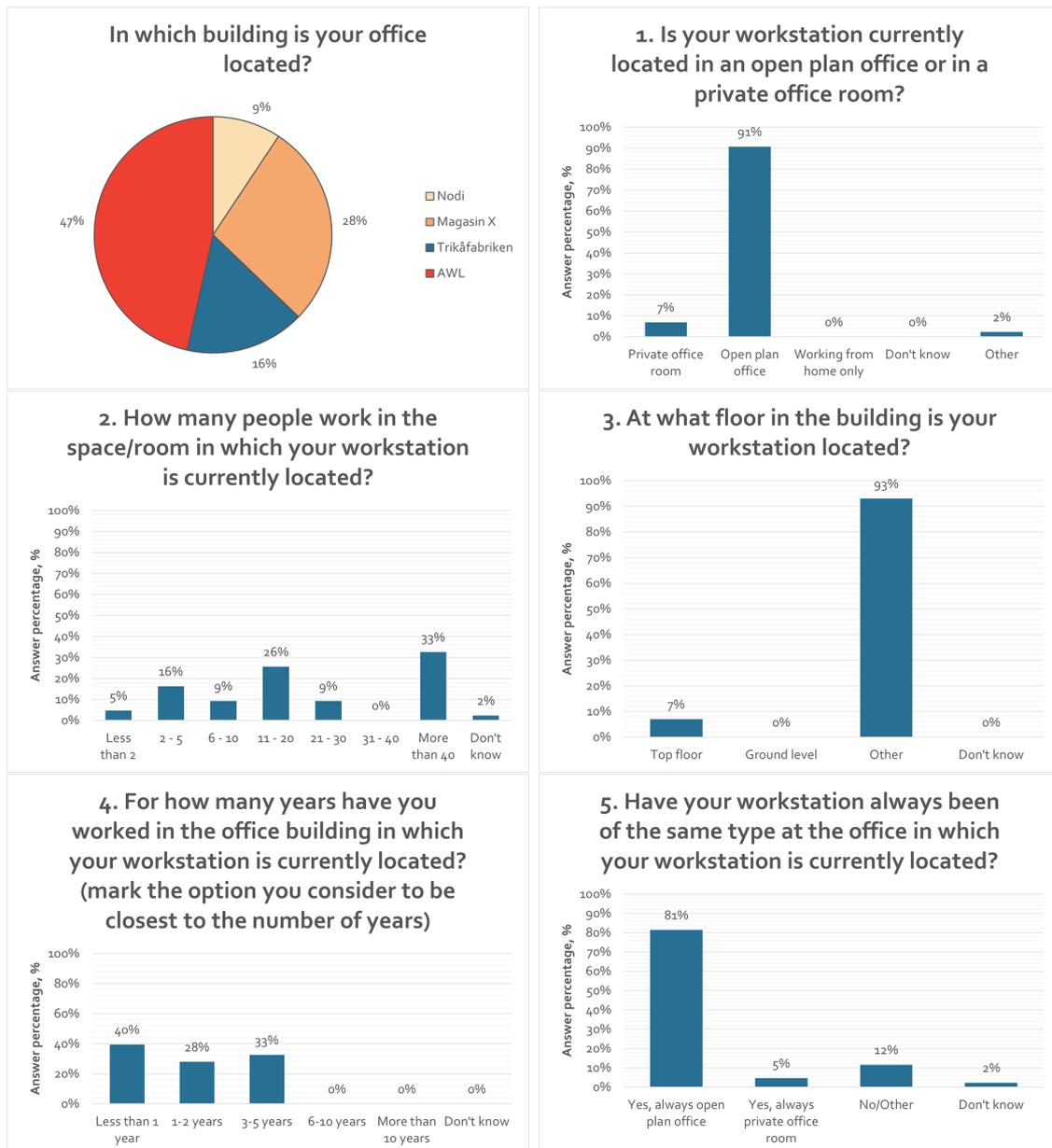


Figure 4.1: The graphs show the results from the questions regarding the subject *general information about the respondents workstation* in the questionnaire distributed to the wooden offices.

In the second group of questions the respondents were asked to assess the acoustic environment of their work area. The questions mainly concerns acoustic disturbances from different sources and how frequently the respondent feels disturbed by it. The results are presented in figure 4.2 and figure 4.3.

The top left graph in figure 4.2 shows the results regarding impact noise. The majority of the answers are distributed in the lower part of the range, meaning that the respondents are not very disturbed by impact noise. Although there are some answers in the higher range, showing that a few of the respondents experience impact noise to be highly disturbing. The frequency of disturbance follows the results

of the level well, with the majority still in the lower half of the range.

The top right graph in figure 4.2 shows that half of the respondents are not disturbed by sounds from ventilation, and it was noted that the respondents from Triåkåfabriken generally answered very low on the scale. Only four individuals of the entire group of respondents from the wooden offices answered in the upper part of the range regarding the level of disturbance, but no one responded that they are often disturbed by ventilation. The results regarding sounds from other installations besides ventilation, e.g. elevators and water flow in pipes, are shown in the middle left graph. Approximately 70% of the respondents are not at all disturbed by sounds from installations, and following this never disturbed by it either. In general the results indicates that sounds from installations are not a large problem. The middle right graph in figure 4.2 show the results regarding disturbance from sounds from machines in the office, e.g. printer, computer and phones ringing. The answers are again in the lower part of the scale, but more evenly distributed between the scores 0, 1 and 2. This shows a small and not very frequent experienced disturbance.

Disturbance from traffic noise is shown in the bottom graph. More than 70% are not experiencing any disturbance regarding traffic noise, and almost 80% estimate that they are never disturbed by it. Only a few people answered that they are disturbed by traffic noise, but just one individual feels frequently disturbed.

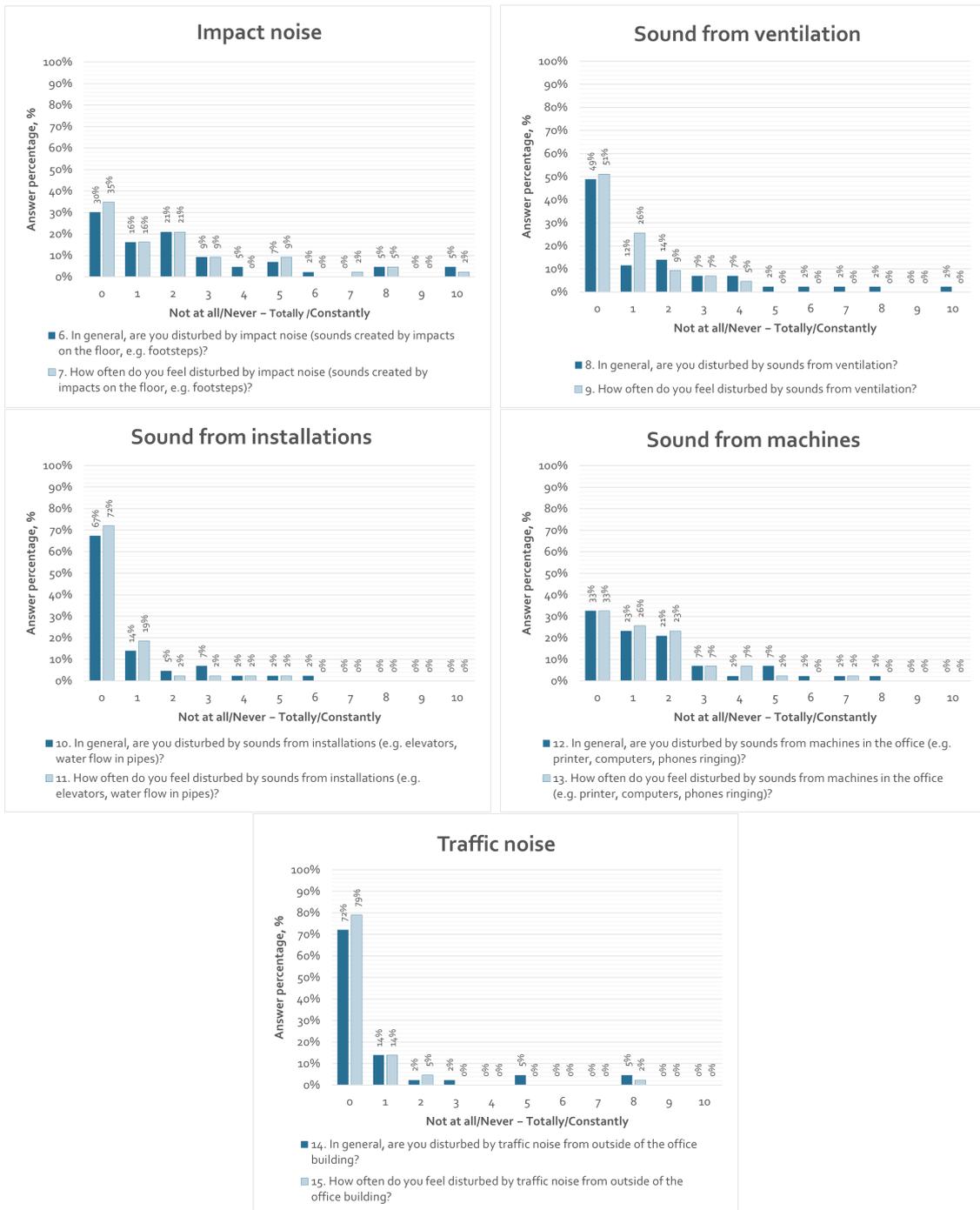


Figure 4.2: The graphs show the results from the questions regarding the subject *assessment of the acoustic environment in the working area* in the questionnaire distributed to the wooden offices, part 1.

In figure 4.3 the top left graph shows disturbance regarding colleagues talking on the phone (including similar options like Teams, Zoom etc.). The results are distributed across the whole scale, with a leaning towards the lower part. The frequency follows the level of disturbance relatively well, except for in the highest scores. Question number 18 and 19 concerns the live conversations between colleagues in the office,

and the result is presented in the top right graph in figure 4.3. The answers to this question is oriented more towards the lower part of the scale, where the majority of the answers are between the scores 1 and 4. A few people considered themselves to be very disturbed by colleagues' conversations. The frequency of disturbance is also generally low for this question.

In the middle left graph the results from the question about sounds from people working are shown. All respondents except for five has answered 3 or below, which indicates low levels of disturbance from these sound sources (e.g. typing on keyboards, shuffling papers). For the frequency, three people have answered above 3 on the score.

The middle right graph in figure 4.3 show the results from the question about sounds from areas outside of the office (e.g. corridors, lunch room, other departments). This result shows that almost half of the respondents are not at all disturbed by sound coming from outside of their office area, but then there are some individuals who have answered 5 or above on the scale. The frequency follows the level of disturbance well. The last question in this group regards sounds through the walls from adjacent rooms. The results are show in the bottom plot in figure 4.3. Again, the majority is in the lower range of the scale, but some answered in the higher range as well. Generally the respondents who answered higher on the scale have their workstation located in AWL, however most of the respondents from AWL still answered in the lower range. The frequency again also follow the level of disturbance well.



Figure 4.3: The graphs show the results from the questions regarding the subject *assessment of the acoustic environment in the working area* in the questionnaire distributed to the wooden offices, part 2.

Figure 4.4 show the results from question number 26 (top graph) and 27 (bottom graph). In these questions the respondents were able to choose more than one option to answer. The results regarding which sound sources the respondents experienced themselves to be most disturbed by at their workstation (question number 26), show clearly that talking colleagues are the main disturbance in the investigated offices.

Both colleagues talking on the phone and in real life was chosen by close to half of the respondents. From the previous questions these sources could be expected to be in the top.

The third most disturbing source is impact noise. A fourth of the respondents also choose the option "Nothing, I am not disturbed by any particular sound in the office". This corresponds well to the general low results of the questions 6 to 25. Traffic noise, installation noise and sounds from machines all have a low answer percentage which corresponds well to the results in figure 4.2. When looking at the respondents who choose "Other" as an alternative it can be understood that some of the respondents from AWL mention that the acoustic environment in the meeting rooms are perceived to be a little bit worse.

By looking at the individual answers from the different offices it can be seen that apart from the results presented in figure 4.4, the respondents from Nodi also answered "Noise from other areas outside the office" and Magasin X answered "Ventilation". A lot of the respondents from Triåkfabriken answered that they are not disturbed by anything in particular, while the answers from AWL are very mixed.

In question number 27 around half of the respondents choose the options "reading" and "computer work" to be the task during which they feel the most disturbed. A third choose "writing" as one of their options. All of these three options are individual work. Almost a fourth of the respondents chose "Nothing, I am not disturbed during any particular task" among their options as well. Very few chose "conversating with colleagues" as a task during which they feel disturbed.

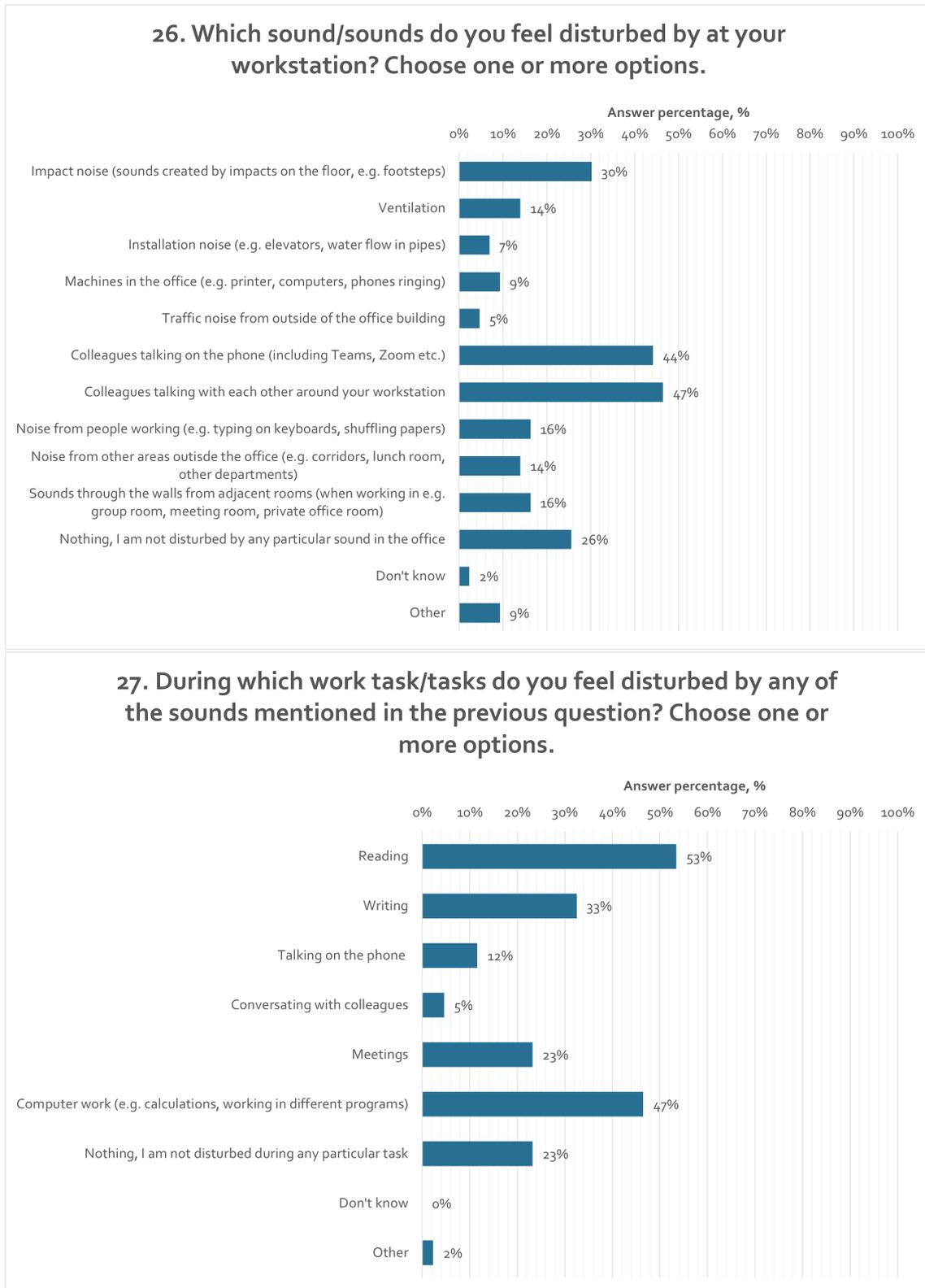


Figure 4.4: The graphs show the results from the questions regarding the subject *assessment of the acoustic environment in the working area* in the questionnaire distributed to the wooden offices, part 3. The respondents were asked to choose one or more answers from the given options.

The next group of questions are on the subject of perception of the acoustic environment. The results are shown in figure 4.5. The answers of question number 28 are presented in the top left graph and show that the respondents in general perceive the acoustic environment of their office to be good. By looking at the individual answers for the buildings it can be seen that all offices except one have a leaning towards the higher range of the scale, while Triåfabriken has a leaning towards the more neutral options. Only two individuals from the wooden offices find the acoustic environment of their office to be really bad, and from the written comments it can be understood that one of these persons is disturbed by music from the floor below.

Question 29 asks if the respondents' concentration is disturbed by sounds in the office, and the results in the top right graph in figure 4.5 show that the majority have answered in the lower range of the scale meaning they are not very disturbed. A few people experience that their concentration is very disturbed, for example the person who was very disturbed by the music from the floor below. In the bottom graph in figure 4.5 the results show that most of the respondents perceive that they can have confidential conversations, but the responses are mixed. The answers vary between the different offices, where the lower scores mainly come from AWL.

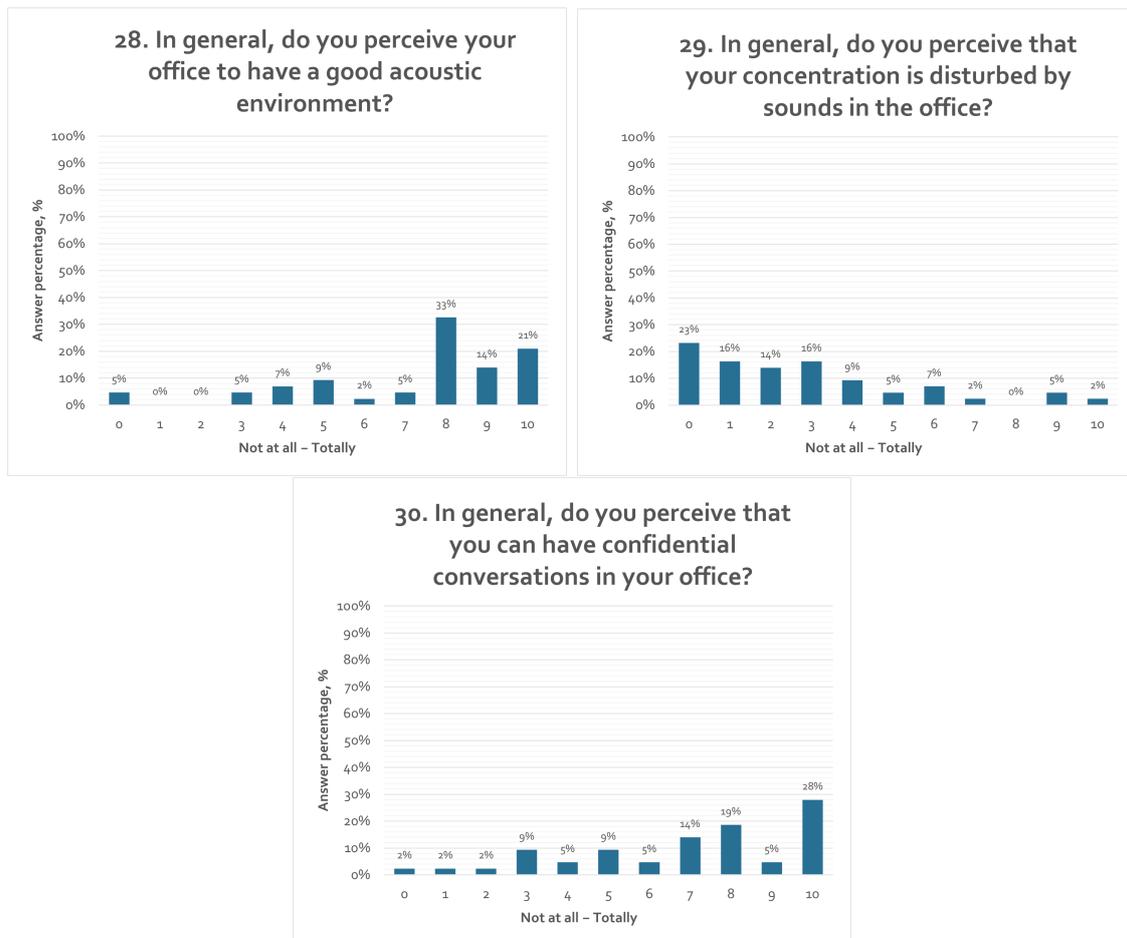


Figure 4.5: The graphs show the results from the questions regarding the subject *perception of the acoustic environment* in the questionnaire distributed to the wooden offices.

In figure 4.6 the result of the question regarding whether or not there is a certain area in the office that the respondent perceive to have a different sound quality is shown. 44% of the respondents perceive that a certain area/areas have a different sound quality. Out of these 21% perceived an area/areas to be extra good, and 58% perceived an area/areas to be extra disturbing. The majority of the respondent from the different offices, except Nodi, answered that the acoustic environment in certain areas are perceived as "Extra disturbing". At Nodi none of the respondents perceived the environment as disturbing and answered "Extra good" or "Don't know" instead. From the written answers to the follow up question asking what area/areas the respondent thinks of, it can be seen that the area most often found to have a different sound quality are meeting rooms. Whether it is extra good or extra disturbing varies between the different offices. When asking why the area/areas mentioned have a different sound quality, it is seen in the written answers that in many cases it depend on ventilation or airborne sound. Several respondents also answered impact noise.

4. Results

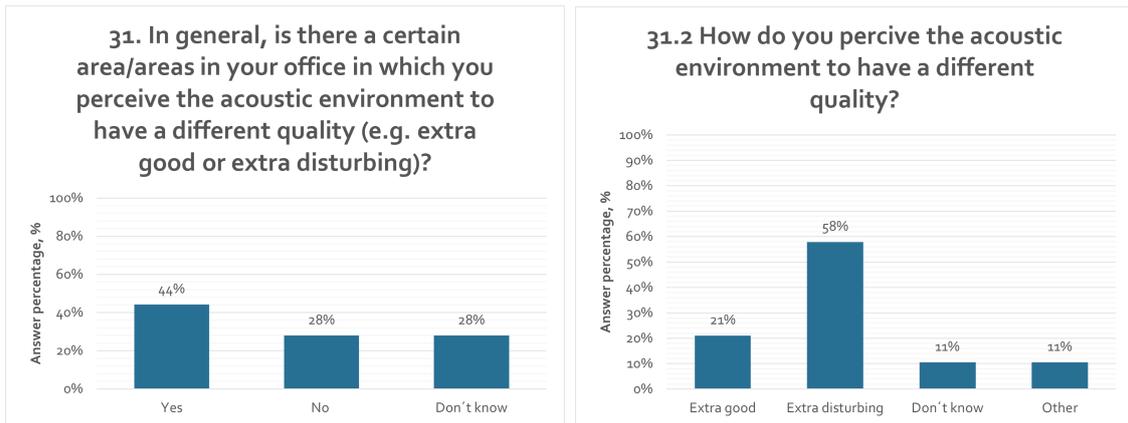


Figure 4.6: The graphs show the results from the questions regarding the subject *perception of the acoustic environment* in the questionnaire distributed to the wooden offices, part 2.

Questions 32 to 34 concerns effects due to the COVID-19 pandemic. The results are shown in figure 4.7. In the top left graph the results show that the majority of the respondents works three days or more in the office, and half of the respondents in general works five days a week in the office. To question number 33 the results are shown in the top right graph. A big part of the response group has answered that they work the same number of days in the office now as before the pandemic. Another part of the group answered that they work less days in the office now compared to before. Very few answered that they work more days in the office now. 16% answered that they do not know.

In the bottom graph in figure 4.7 the results show that most of the respondents do not experience a differences in the acoustic environment now compared to before the pandemic, or they do not know. This is expected due to how newly built the offices in the study are. From the respondents answering "yes" it can be noticed from the written answers in the follow up questions that the main reason is that more people are at the office now, which creates more sound.

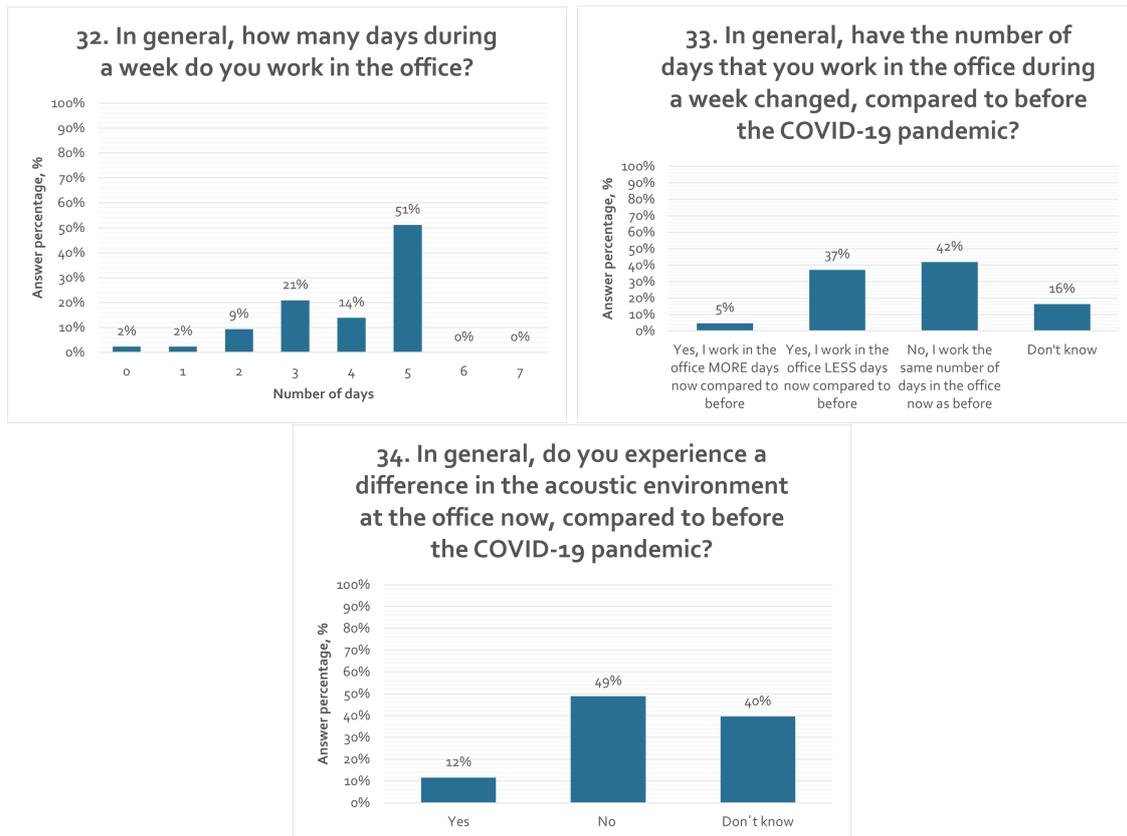


Figure 4.7: The graphs show the results from the questions regarding the subject *effects on the workstation due to the COVID-19 pandemic* in the questionnaire distributed to the wooden offices.

The last group of questions asks for general information about the respondent. The results are presented in figure 4.8. From the top left graph it can be seen that it is the same amount of females and males who responded to the questionnaire, and one person who preferred not to say. When looking at the individual answers from the different offices the distribution between female and male are still very equal. The distribution over age are shown in the top right graph in figure 4.8. The biggest age group among the respondents are 26 to 35 years old. The age groups 36 to 45, 46 to 55 and 56 to 65 are approximately a fifth of the respondents each. In the age group 18 to 25 there are three respondents. Only one person is older than 65, and no one is younger than 18. At both Nodi and Triåfabriken the majority of the respondents are in the older age range, while at AWL and Magasin X the distribution is more equally spread. The bottom left graph show that a clear majority of the respondents consider themselves to have normal hearing. From the respondents, 70% consider themselves to not be extra sensitive to noise, 23% think they are and 7% are unsure. This can be seen in the bottom right graph.

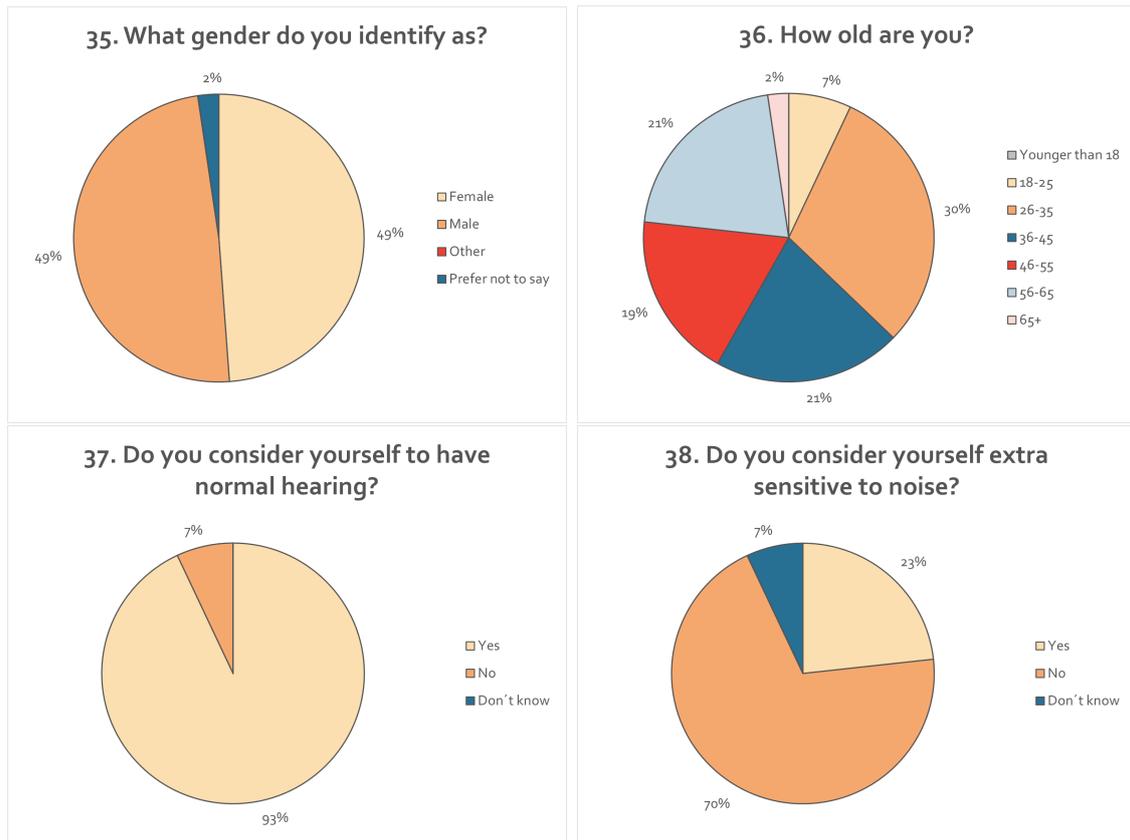


Figure 4.8: The graphs show the results from the questions regarding the subject *general information about yourself* in the questionnaire distributed to the wooden offices.

4.2 Comparison of the Questionnaire Results for the Different Office Types

Apart from the wooden offices investigated, three concrete offices and one office that is a mixture between older buildings in concrete and a newly built wooden construction connecting them (here on called "combined office" in the report) are investigated. The total number of answers from the concrete offices is 122, with 87 answers from AFRY in Stockholm, 20 answers from Johanneberg Science Park in Gothenburg and 15 answers from AFRY in Gothenburg. From Trafikverkets headquarters in Borlänge, which is the combined office, the total number of answers is 164. This gives a total of 329 answers to the questionnaire when adding all offices investigated in the thesis.

For all offices investigated, the most common office layout was open plan office, but from the written answers it is understood that many of the respondents answering "open plan office" sits in an activity-based layout (e.g. Trafikverket and AFRY in Stockholm). The answers to question number 2 "How many people work in the space/room in which your workstation is currently located?" are spread over the

whole range of intervals for all three office types. Regarding on which floor the respondents are located, it is noted that for both the wooden offices and the concrete offices the majority sits on another floor than top- or ground level, but for the combined office almost half have their workstation located on the top floor and a third on ground floor.

When being asked about how many years the respondent have worked in their current office building, it is noted that the answers for concrete have a much bigger spread. This is due to some of the concrete buildings investigated are several years older than the wooden offices and the rebuilt combined office. The workstations of the respondents in the wooden and concrete offices have mainly always been of the same type, while the workstations in the combined office have changed from private office rooms to activity-based layout.

In figure 4.9 the graphs shows the results of question 6 to 15, which are part of the chapter about acoustic environment of the respondents work area, for all three office types. In the top left graph the answers regarding impact noise is shown. It can be seen that the respondents from the concrete and combined offices have in a higher degree than the wooden offices answered on the upper part of the scale. It is the same for both questions regarding impact noise.

In the top right graph in figure 4.9 the results regarding sounds from ventilation are presented. It is noted that around 20% more respondents from the wooden offices answered 0 on the scale compared to the concrete offices. Although, in general the majority of all offices answered on the lower part of the scale for question number 8 and 9. The results from the questions about sounds from installations is shown in the middle left graph in figure 4.9. The few answers in the higher part of the scale comes from the concrete and combined offices. In general the concrete and combined offices have chosen higher options on the scale than the wooden offices, but over 40% from all of the office types have chosen 0.

The results from questions number 12 and 13 about sounds from machines are shown in the middle right graph in figure 4.9. The answers to these questions are more evenly distributed over a larger range of the scale. Comparing the answers from the wooden and concrete offices, it can be seen that while the wooden offices peaks at 0 the concrete offices peaks around 2 and 3 on the scale. The bottom graph in figure 4.9 show the results from the questions about traffic noise. It can also be seen that the respondents from the concrete offices are more disturbed by traffic noise than participants from the other office types.

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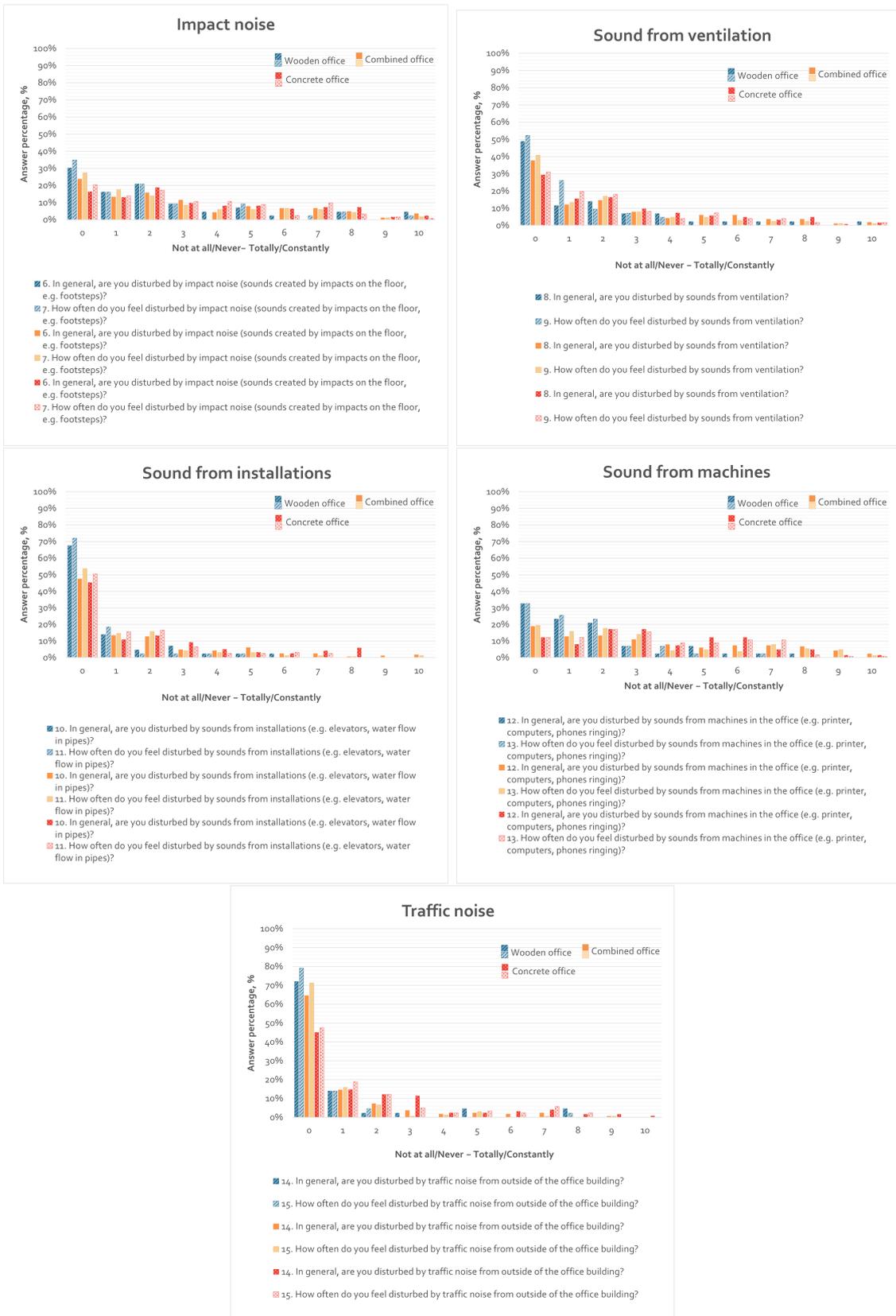


Figure 4.9: The graphs show the comparison for wooden-, combined- and concrete offices from the questions regarding the subject *assessment of the acoustic environment in the working area* in the questionnaire, part 1.

Figure 4.10 show the results for questions 16 to 25 which are also part of the chapter about acoustic environment of the respondents workstation. The top two graphs show the results regarding colleagues talking on the phone (including e.g. Teams and Zoom) and colleagues conversating with each other around the respondents work area. From the graphs it can be seen that the concrete and combined offices have more answers in the higher range of the scale than the wooden offices. Their answers are distributed over the whole scale with no clear peaks, while the wooden offices peaks in the lower range.

The middle left graph in figure 4.10 shows the results regarding sounds from people working. The answers from all three office types follow each other rather well for these questions, with the exception that wooden offices have no answers in the three highest options on the scale. In the middle right graph the results from question number 22 and 23 regarding sounds from areas outside the office (e.g. corridors, lunch room, other departments) are presented. It can be seen that a bigger part of the respondents from the wooden offices have answered 0, but the majority of all office types have answered 3 or less. Only a few people from each office type have answered 10. The last graph in figure 4.10 show the results to question number 24 and 25 about sounds through the walls from adjacent rooms. The results from the wooden and the concrete offices are similar, while the combined office have almost half of the answers at 0.

4. Results

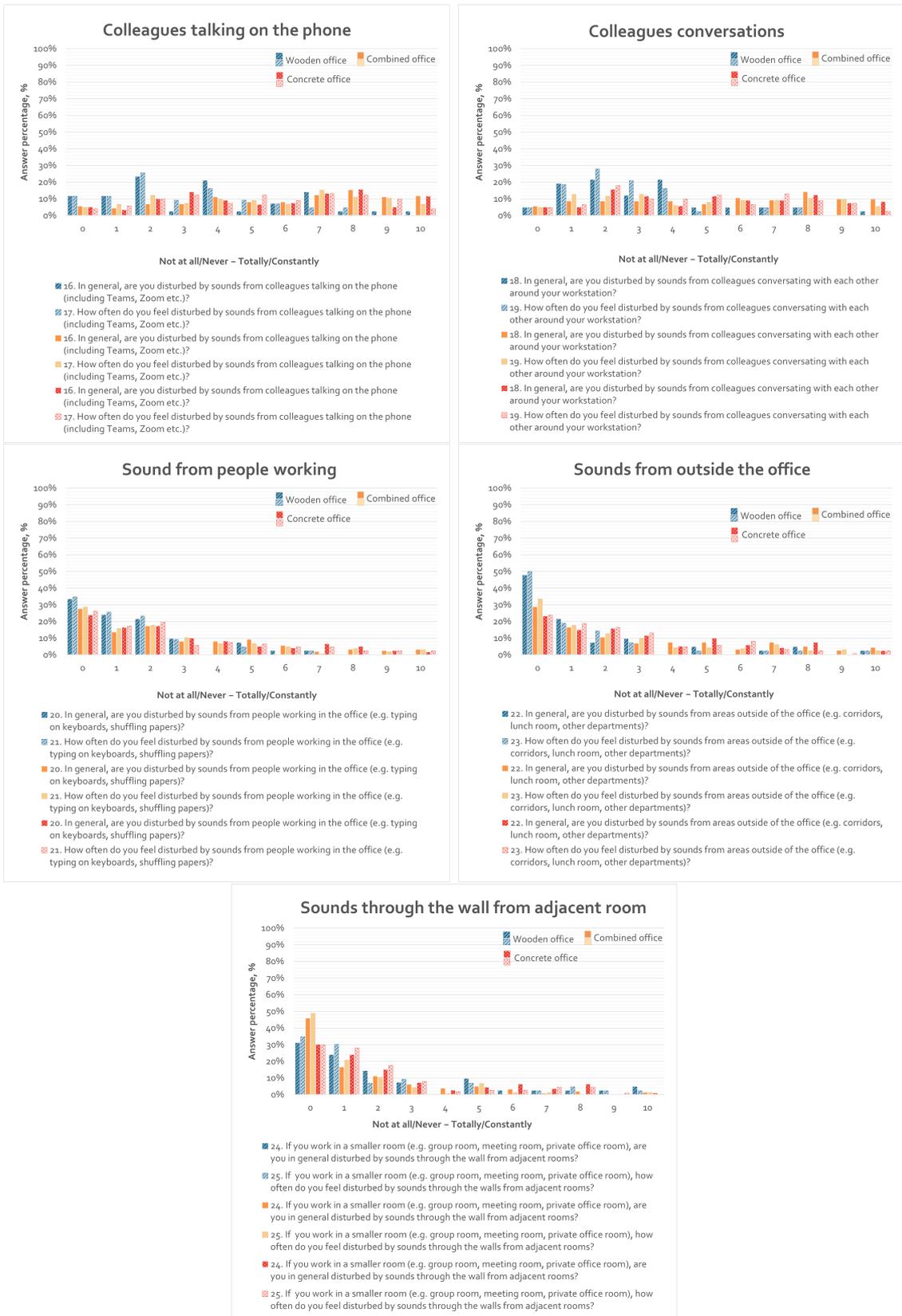


Figure 4.10: The graphs show the comparison for wooden-, combined- and concrete offices from the questions regarding the subject *assessment of the acoustic environment in the working area* in the questionnaire, part 2.

The results of questions 26 and 27 regarding *assessment of the acoustic environment in the working area* are shown in figure 4.11. In question 26 the graph shows that for all three office types it is colleagues talking in different forms that is what people find most disturbing, but the options have a much higher answer percentage from both the concrete and combined offices than the wooden offices. For the concrete and combined offices it is sounds from machines and sounds from areas outside the office that also stands out a bit, but far less respondents choose this than the option with colleagues talking. This differs from the wooden offices where it instead is impact noise and "Nothing, I am not disturbed by any particular sound" that have slightly larger answer percentage. Only 5% of the respondents from the concrete offices choose installation noise. From the combined office the option with the least responses is traffic noise, which is the same for the wooden offices.

In the bottom graph in figure 4.11 the result from question number 27 is shown. The top three option for all offices are reading, computer work and writing. Again there are a lot more answers on the option "Nothing, I am not disturbed by any particular sound" for the wooden offices than the other types. All three office types have meetings in the top five among the options. For wooden offices it is the same percentage as for the "nothing"-answer, and for the combined office it is close to the percentage for "talking on the phone". The work task during which the respondents feel the least disturbed for all three office types is "Conversating with colleagues".

4. Results

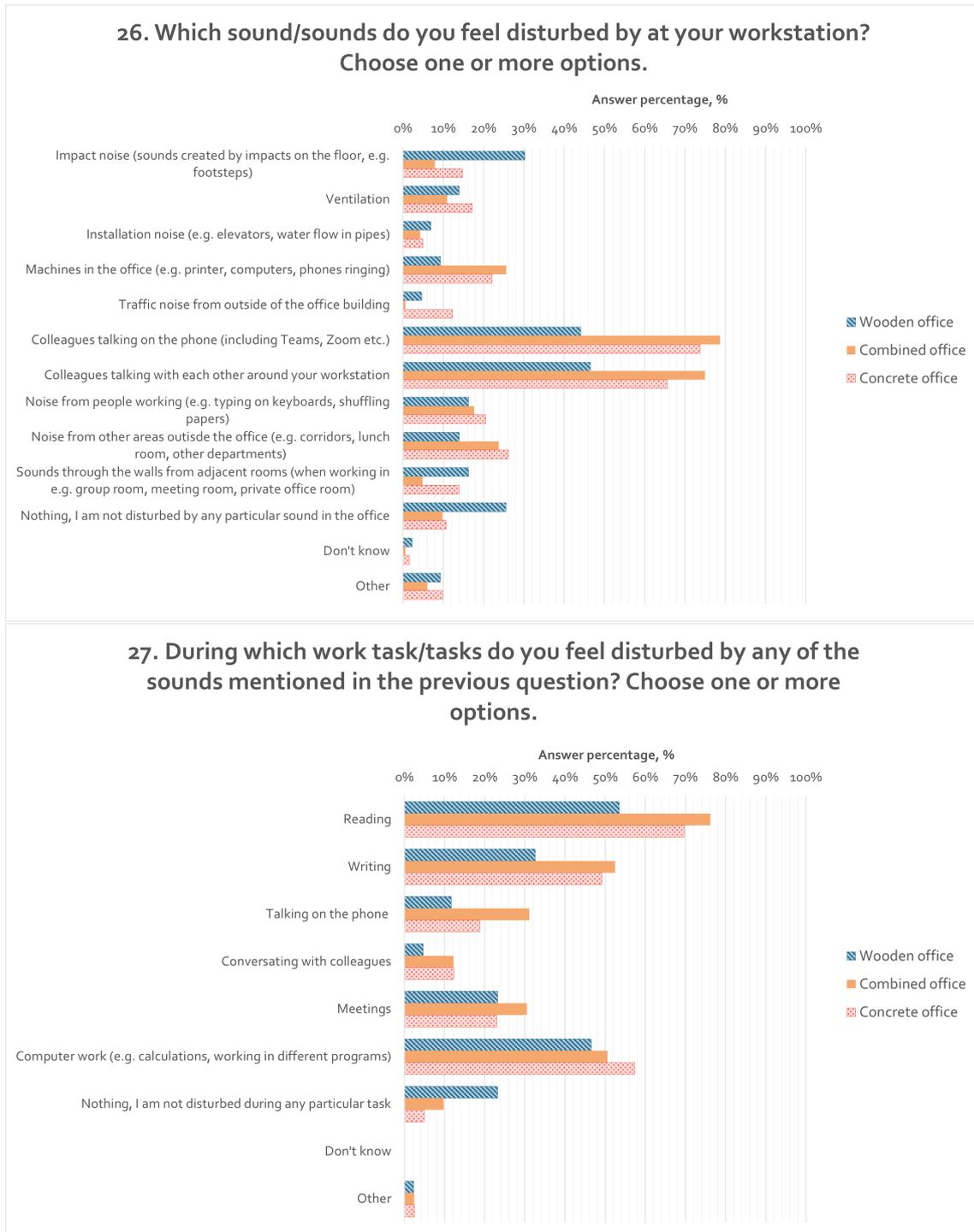


Figure 4.11: The graphs show the comparison for wooden-, combined- and concrete offices from the questions regarding the subject *assessment of the acoustic environment in the working area* in the questionnaire. The respondents were asked to choose one or more answers from the given options.

The responses to the chapter about perception of the acoustic environment is presented in figure 4.12. The results for question number 28 are presented in the top left graph and show that the majority of the respondents from all three office types

have answered 6 or higher on the scale, indicating that they in general perceive the acoustic environment of the offices to be good. For both the wooden office and the combined office at least half of the respondents have answered 8 or higher on the scale, while for the concrete office only a third of the respondents answered 8 or higher. It can also be seen that a bigger percentage of the respondents answered 3 or less for the concrete offices than for the other two types.

In the top right graph the result to question number 29 regarding disturbance of the employees concentration is presented. Around 40% of the respondents from the concrete and combined office have answered 6 or higher on the scale, indicating that more than a third of the people perceive their concentration to be significantly disturbed by sounds in the office. About the same percentage of the respondents for these two office types have answered 3 or less, indicating that a lot of people does not perceive their concentration to be disturbed either. For the wooden office the percentage answering 3 or less is a lot bigger, 70%.

The bottom graph in figure 4.12 shows the result to question number 30. It is clear that the participants from the wooden offices have answered more towards the higher part of the scale than the concrete and combined offices. The combined office is more or less evenly distributed between the higher and lower range of the scale, while the concrete office have a slight leaning towards the lower part of the scale.

4. Results

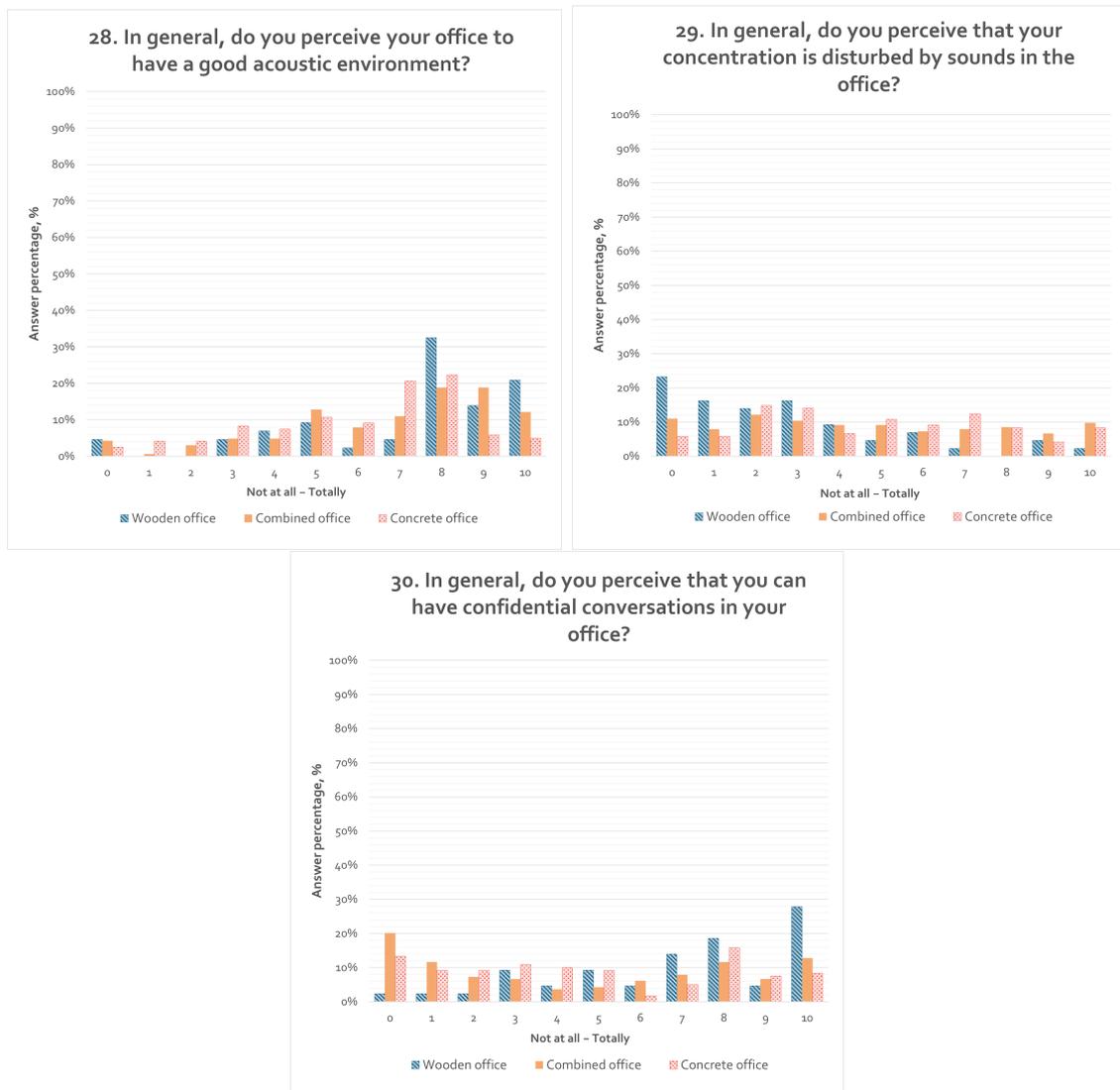


Figure 4.12: The graphs show the comparison for wooden-, combined- and concrete offices from the questions regarding the subject *perception of the acoustic environment* in the questionnaire.

For question 31 and its follow up questions regarding areas in the office with a perceived different acoustic quality the results are presented in figure 4.13. It is about the same percentage of answers in all three categories for all three office types. Between 40% to 50% have answered that there is a certain area/areas in their office that they perceive to have a different acoustic quality.

From the written answers it is understood that it is the lunch room and coffee areas, smaller rooms (e.g. meeting rooms) and corridors that have different qualities. The smaller rooms are perceived as extra good, the lunch room and coffee area as extra disturbing, and the corridors are unspecified but some comments indicates that they are perceived negatively. For the concrete offices it is slightly more people who have answered "Extra good" than who answered "Extra disturbing". In the written answer it is noticed that the smaller meetings rooms are perceived as extra good

due to extra sound insulation and less noise, while lunch room and common areas are perceived as extra disturbing due to again a larger amount of people. The result from the wooden offices are discussed in section 4.1.

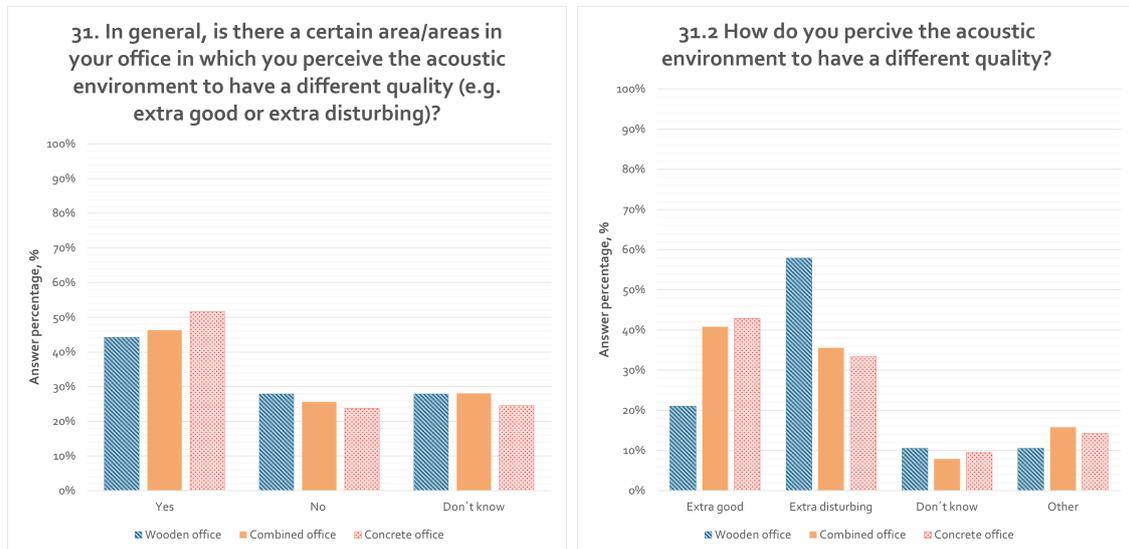


Figure 4.13: The graphs show the comparison for wooden-, combined- and concrete offices from the questions regarding the subject *perception of the acoustic environment* in the questionnaire, part 2.

4.3 Statistical Analysis of the Questionnaire Results

In figure 4.14 the statistical result for the different office types are shown. The upper graph shows the mean value for question 6 to 25 (see appendix A), which in the questionnaire represents the questions regarding the assessment of the acoustic environment of the respondents work area. In the graph the standard deviation for each question is also shown. By looking at the graph it is clear that question number 16 to 17 as well as 18 to 19 is rated to be most disturbing by all different office types. These questions concerns colleagues talking in different kinds of forms. Questions 10 to 11 as well as 14 to 15 is perceived as the least disturbing noise within the office. These questions regards the installation noise as well as the traffic noise. For the majority of the questions both the concrete- and combined offices have similar mean values, and they are generally rated higher on the scale than the wooden offices.

No mean values for the offices are above 6, which indicate low levels of disturbances for all proposed noise sources. The mean value for the wooden offices are below 4 for all questions, while the mean value for both the concrete- and combined offices are rated a little bit higher. This indicates a lower disturbance in the wooden offices. However, for question number 24 to 25 the respondents in the wooden offices have rated the perceived disturbance as higher than the two other office types. These questions regards sounds through the wall from adjacent rooms. When looking at

the mean value for the concrete offices in comparison to the two other office types it is clear that the respondents generally answered higher on the scale, but with small margins. Although this does not apply for the questions regarding talking colleagues and sounds from areas outside the office. In general for all questions and all office types the frequency of disturbance is always rated lower than the level of disturbance.

When looking at the standard deviation for each question it is clear that the deviation is large. This indicates a wide spread of the answers. Some of the standard deviations shown goes below zero since the graph shows the mean value ± 1 standard deviation, but the negative values are not shown in the graph since the scale is kept the same as used in the questionnaire.

The lower graph in figure 4.14 again shows the mean value for questions 6 to 25 (see appendix A), but in this case with the confidence interval for the probability of 95% for each question calculated for the whole population of answers. When looking at the graph it can be seen that the confidence interval for the wooden offices is slightly larger than for the two other office types. The combined office type have in general a slightly smaller interval than the concrete offices. This is due to the different number of responses obtained for the different office types. Fewer answers give a larger confidence interval.

It can be seen that the confidence interval for the concrete- and the combined offices overlap, which means that there is no major difference, except for question 14 and 15 about traffic noise. To find statistical significant differences, further statistical computations has to be made. Between the wooden- and the concrete offices some differences can be seen. For five groups of question (10 and 11, 12 and 13, 16 and 17, 18 and 19 as well as 20 and 21) the confidence interval does not overlap, neither for how disturbed the respondents are or how often. For question 9 and 22 differences in confidence interval can also be observed. The confidence interval indicate that if the general population working in the offices would have answered the survey, the mean value of all answers would be placed somewhere within the given interval for each question. However, the confidence interval is based on the number of responses received in the questionnaire, which was a rather small sample size and it is not known if the group is representative to be able to draw conclusions for the whole population of office workers in general.

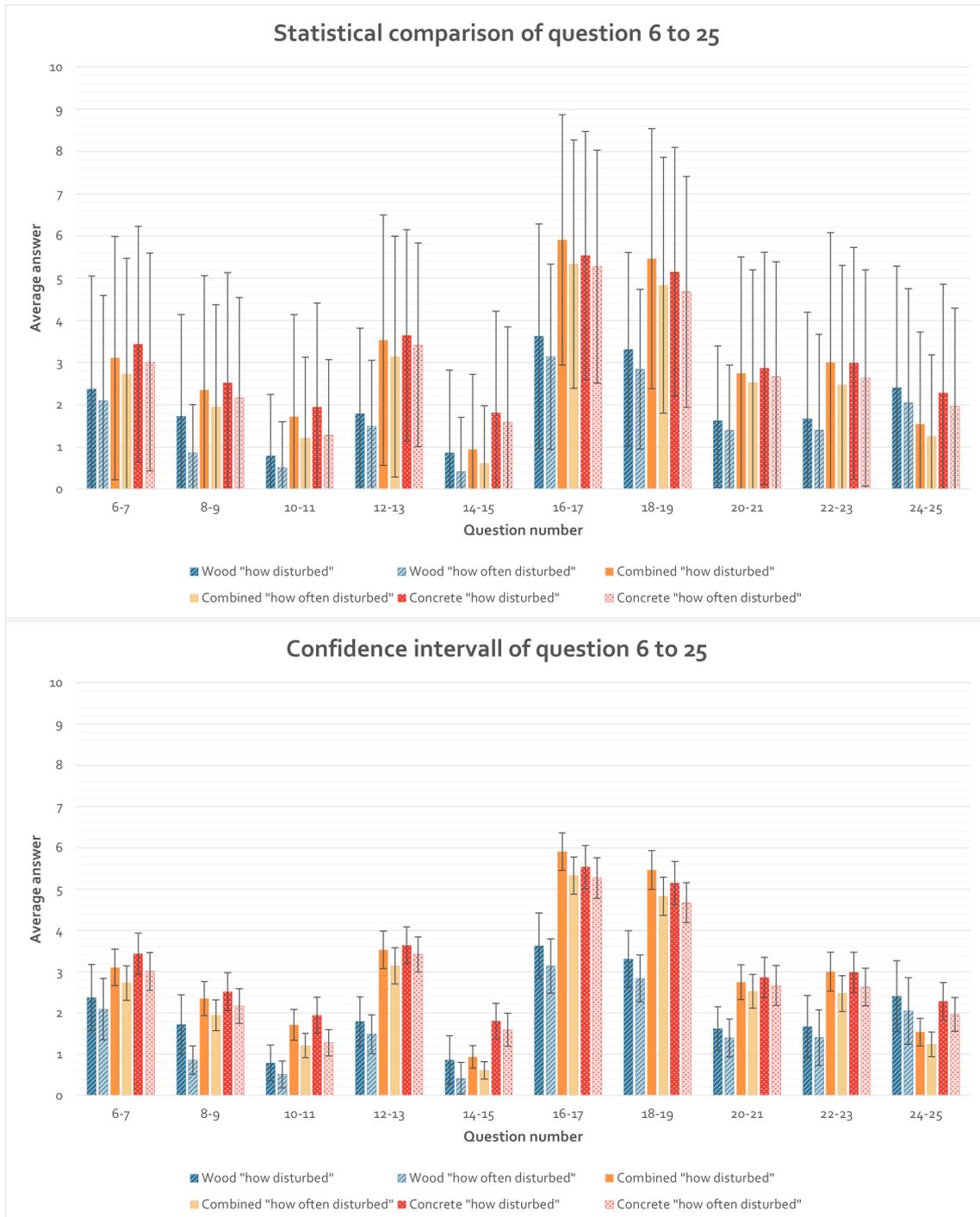


Figure 4.14: The graphs show the mean value, standard deviation and confidence interval for the probability of 95% for wooden-, combined- and concrete offices from the questions regarding the subject *assessment of the acoustic environment in the working area* in the questionnaire.

In figure 4.15 the statistical result for the different office types are shown. In the graph to the left the standard deviation of questions 28 to 30 (see appendix A) is shown, while the confidence interval for the probability of 95% calculated for the whole population of the answers is shown in the right graph. Both graphs show

4. Results

the mean value. When looking at the statistical comparison the mean value for the wooden offices is better (higher for question 28 and 30, and lower for question 29) for all three questions. For question 28 regarding how good the acoustic environment is perceived to be in the office area, all respondents perceive it to be good in general. For question 29 regarding how disturbed the respondents concentration is due to office noise, it can be seen that the respondents in wooden offices generally are less disturbed, while both the combined- and concrete offices answered more neutrally. For question 30 regarding if the respondent perceive that they can have confidential conversations within the office area the wooden offices are as well rated higher in comparison to the other office types. Here the combined- as well as the concrete offices are rated to the more neutral part of the scale.

When looking at the right graph in figure 4.15 it can be seen that the confidence intervals for the wooden offices are slightly larger than the combined- and concrete offices. For question 28 it is noticed that the confidence intervals overlap for the different office types. This shows that there is no major difference found in how the acoustic environment is perceived without doing further statistical computations. For both question 29 and 30 regarding how disturbed the respondents concentration is as well as if they perceive that they can have confidential conversations, a difference in confidence interval can be observed between the wooden offices and the two other types.

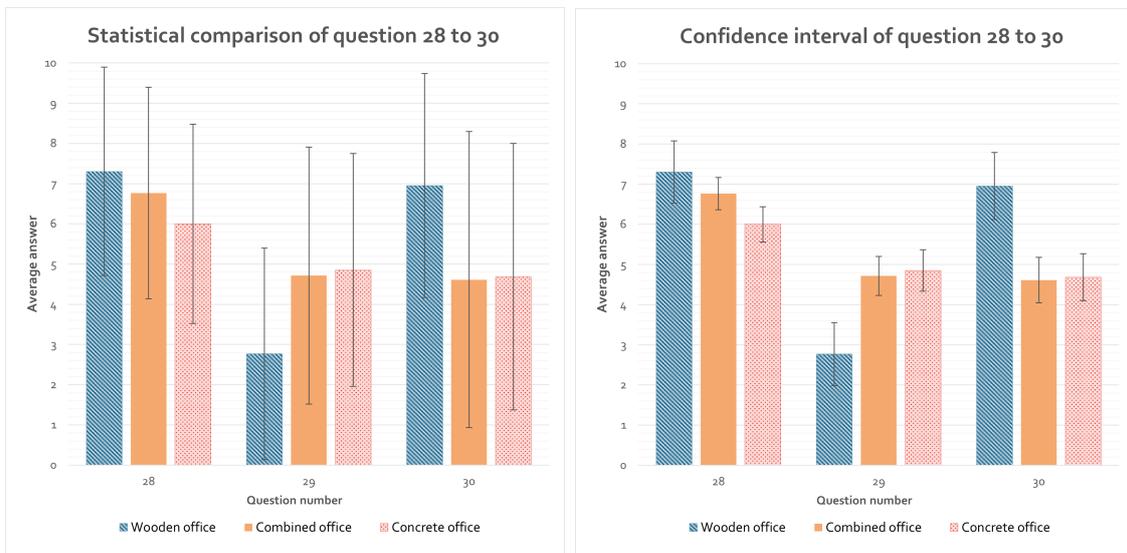


Figure 4.15: The graphs show the mean value, standard deviation and confidence interval for the probability of 95% for wooden-, combined- and concrete offices from the questions regarding the subject *perception of the acoustic environment* in the questionnaire.

4.4 Correlation with Measurement Data

In this section the collected available measurement data from previous measurements are analysed. The four different parameters investigated are airborne sound

insulation as reduction index (R'_w), impact sound level ($L'_{n,Tw}$), reverberation time ($T_{20}(T_{20,125Hz})$) and installation noise ($L_{A,eq}/L_{C,eq}$). The measurement data is not presented directly because of confidentiality and data ownership. If needed to see the data values contact has to be made with the owners of the measurement reports. Not all buildings have measurement data for all parameters in the measurement reports collected for this thesis. The measurement data analysed are the latest available measured data, and possible modifications of the construction after the measurements are not accounted for here.

4.4.1 Airborne Sound Insulation

The airborne sound insulation have been measured using apparent sound reduction index (R'_w) for all four wooden offices, one of the concrete offices and several buildings of the combined office. When comparing the results of the measurement data of airborne sound to the results from the questionnaire, it is mainly questions number 22 to 26 and 28 to 31 (see appendix A) that are of interest. It was understood from the questionnaire that the respondents in general are not very disturbed nor often disturbed by sounds from outside the office or from adjacent rooms, which correlates to that almost all the buildings have a better sound class than BBR (the lowest requirement regarding to the standard, sound class C in BBR (Boverkets byggregler)). From the measurement data it is noticed that two of the wooden buildings have reduction indices that are several dB better than the requirement. It is also noticed in the answers from the questionnaire that the respondents from the wooden offices are slightly more pleased with the overall acoustic environment of their offices, perceive their concentration to be less disturbed and feel to a higher degree that they can have confidential conversations.

When asked about areas with a different sound quality, the respondents of the wooden offices in general answered "extra disturbing" and commented on the meeting rooms where one problem seems to be the airborne sound. This does not correlate completely to the measurement results since some of the wooden buildings have higher measured reduction index than the requirement for the same type of rooms that the respondents feel are extra disturbing.

4.4.2 Impact Sound Level

For impact sound level, $L'_{n,Tw}$, data was found for all of the wooden offices, one of the concrete offices and several buildings of the combined office. The findings in the measurement data can be compared to questions number 6 and 7, 26 and number 31 (see appendix A). Question 6 and 7 directly ask the respondents about impact noise and it was found that the mean value for all office types is below 4 on the scale, which correlates well to the measurement data that show much better levels than required.

In question number 26 in the questionnaire the results show that about a third of the respondents from the wooden offices answered that impact noise is one of the

sources that they feel disturbed by at their workstation. From the measurement data it is seen that AWL is one of the offices that have the smallest margins to the requirements, and from the comments in question 31 it is noted that some of the respondents from AWL are experiencing disturbances from impact noise in the meeting rooms. It should also be noted that AWL is designed for the minimum requirement according to BBR and sound class C. From the concrete offices only half as many people choose impact noise as an option in question number 26 even though they have the highest mean for question 6 and 7. Comparing to the measurement data for JSP 1 it is noted that the deviations are large for the two existing requirements, which indicates much better levels than designed for, but no clear connections can be found here. When looking at the comments in question 31, no one from the concrete or combined offices has commented about impact noise. This indicates a weak but existing connection to the measurement data which show that all the buildings fulfill the requirements and slightly higher.

4.4.3 Reverberation Time

The reverberation time, T_{20} , has been measured for all of the four wooden offices, one of the concrete offices as well as for several buildings in the combined office type. Looking at the measured averages it can be noted that the majority of the offices are within the range 0.4 s to 0.6 s, and thereby has an acoustic environment sufficient for speech. When looking at the results from the questionnaire, especially question number 28 to 30 (see appendix A), it can be understood that the majority of the respondents perceive the acoustic environment within the office to be good, particularly in the wooden offices. The respondent from the wooden offices perceive their concentration to be less disturbed than the respondents from both concrete- and combined offices. It can also be understood that the respondents in wooden offices perceive that they can have confidential conversations to a higher degree than the two other office types. This does not correlate especially well with the measurement results since the wooden offices have a measured average that is generally longer than the concrete- and combined offices. It is however hard to draw conclusions since the spaces in the majority of the wooden offices have been furnished after the measurements were made.

4.4.4 Installation Noise

The installation noise has been measured for common service equipment in three of the wooden offices, one of the concrete offices as well as one building in the combined office. The equivalent continuous sound pressure level is measured for both A-weighted, $L_{A,eq}$, and C-weighted, $L_{C,eq}$, conditions. The majority of the offices have a large margin between the requirement and the measured average, indicating that the installations are quieter than they are required to be. In the three wooden offices, Nodi, Magasin X, and AWL, the ventilation system are demand-controlled. The airflow will change depending on the number of people in the room and thereby the sound pressure level as well. When fewer people are in the room the ventilation

systems will be quieter than if a large number of people are present for a longer time. It can also be observed that all of the offices are designed for sound class B, but in both Magasin X and the concrete office JSP 1 the majority of the measurements meet the criteria of sound class A.

When comparing the measurement data to the questions regarding installation noise in the questionnaire, questions 8 to 10 as well as question 26 (see appendix A), it can be noted that the majority of the respondents are not disturbed by installation- or ventilation noise. This correlates well with the results from the measurement data since all of the measured sound pressure levels are below the highest level that the requirement states. It was understood from the questionnaires that the respondents in the wooden offices are in general slightly less disturbed by installations and ventilation systems than the respondents in both concrete- and combined offices. However, from question 31 in the questionnaire (see appendix A), it can be understood that some of the respondents from the wooden offices perceive the acoustic environment to be "extra disturbing" in meeting rooms due to loud ventilation. This statement does not correlate especially well with the measurement results since all of the measured averages are below the requirements, but it should be kept in mind that the measurements are done for 5% of the spaces only to verify the acoustics of the building. It is therefore unknown if the values in all meeting rooms are the same, and the comments from the questionnaire might therefore be on rooms that are not measured.

5

Discussion

In this chapter the results and used methods are discussed. From the results it is mainly the major findings that stood out that are brought up and reflected on. The results from the scale questions in the questionnaire are discussed based on that 5 on the scale is neutral, and that answers below 5 therefore represent a disturbance at an acceptable level and above 5 a disturbance at an unacceptable level. In the method discussion it is questioned whether or not the used methods turned out to be the most efficient way to obtain the results. Challenges encountered during the way are also reflected on. At the end of the chapter there is a short discussion about ethical aspects and a suggestion of topics to investigate further.

5.1 Discussion of the Results

The results are mainly divided into three parts, a presentation of the questionnaire results from the wooden offices, a comparison of the answers from all of the offices including a statistical comparison, and an analysis of collected available measurement data. Overall a total of 329 answers were received, out of which a half of the respondents were from Trafikverket and 43 from the wooden offices. This means that 13% of the respondents have workstations that are located in wooden offices. The main purpose of the thesis is to investigate the acoustic environment on wooden offices, but since the answer response is low for this office type and it is not known if the group is representative for the whole population it becomes hard to draw any general conclusions and the results can only be interpreted as indications of the acoustic environment in the studied offices. Regarding the response rate from the four different wooden offices, the distribution is skewed, with almost half of the answers from the same office which can be problematic since the constructions are different for the four wooden offices.

5.1.1 Questionnaire Results from Wooden Offices

Since the main purpose was to investigate the acoustic environment in the wooden offices, a large part of the result focuses on analysing the responses from the employees working in wooden offices. The answers to all of the questions were studied individually and for some questions there are certain things worth discussing. Regarding question number 2 in the questionnaire "How many people work in the space/room in which your workstation is currently located?", it can be hard for the

respondents to define how many people that work in the same space as them, especially if it is an open plan office layout or an activity-based layout. Thereby the answers to this question might be a little bit unclear. For question number 5 (see appendix A) it was understood from the written answers that the question has been misunderstood by the respondents. The responses to the question contain answers regarding comparison to workstations in other offices not part of the study as well as answers about activity-based office layout.

For question number 6 regarding impact noise the answers from the wooden offices are lower than what was expected at the beginning of the thesis. Based on the literature study it was understood that impact noise is a common problem in wooden constructions due to its light weight, but from the questionnaire result it is noted that the respondents in the wooden offices mostly experience an acceptable level of disturbance from it, indicating it might not be a large problem. The theory however is mainly based on research in residential buildings, and the tolerance of impact noise might differ from a living environment compared to an office environment. Perhaps people are more tolerant to impact noise at the office for various reasons, but that would need to be further investigated. One reason could also be the usage of shoes at the offices, which can dampen the impact of the steps. Another interesting observation regarding the impact noise in the wooden offices is the difference between the answers in question number 6 and number 26, as well as the written comments in question 31 (see appendix A). From question number 6 it is understood that the respondents are not very disturbed by impact noise, but in question number 26 they rank impact noise as the third most disturbing source. In the written answers later in the questionnaire several respondents from AWL also mentions impact noise in the form of footsteps as a reason why the smaller meeting rooms have an extra disturbing sound quality. The reason for this difference might be due to the question formulation. In question 6 it is asked what the respondents feel in general, while question 31 asks for a certain area. If the respondents do not use the smaller rooms particularly often, they might not consider this disturbance when answering about the impact noise in general and therefore chose a low option on the scale. The expectation on the sound environment in the smaller rooms might also be different from that in the open plan office, in the way that the employees use the rooms for extra concentration or conversations. In question 26 the results perhaps differ from question 6 due to that the different sources are being put in relation to each other.

It can be understood from question number 27 (see appendix A) that the highest-rated work tasks that respondents feel most disturbed during are individual work tasks, such as reading, computer work, and writing. These are tasks that require focus and concentration, which might be the reason why the sounds are perceived as more disturbing during them. This is strengthened by the theory. The least chosen option was "Conversating with colleagues" followed by "Talking on the phone". These are work task where the respondents themselves create sounds and might therefore not register other sounds as much. Due to this the respondents might not be as disturbed during these tasks.

Regarding question number 28 and 29 (see appendix A) the scales are flipped opposite in what can be considered the positive and negative answer. For question number 28 a high number equals a good acoustic environment, while for question 29 a high number instead means that the respondents concentration is very disturbed. This might create confusion for the respondents regarding how to answer the question. However, this is not something that can be clearly seen in the results which makes it possible to believe that the answers correctly reflect the respondents perception. It is also worth to discuss the answers from Trikäfabriken for question number 28, where the majority of the respondents answered on the low or neutral part of the scale. This is unexpected since the majority of the respondents indicated that they are not particularly disturbed by anything at all in questions 6 to 25 (see appendix A). Also in question 26 the majority of the respondents from Trikäfabriken chose the option "Nothing, I am not disturbed by any particular sound in the office". One possible explanation for this is that their office environment could be too quiet, but this would need to be further investigated.

An attempt was also made to identify differences in the acoustic environment before and after the COVID-19 pandemic, but it did not go according to plan. For the wooden offices the comparison is not really possible since most of the offices were still under construction during the start of the pandemic. The employees therefore have no "before" to compare with. Due to this a lot of respondents answered the question as a comparison between how it was during the pandemic and how it is now. This would also have been interesting to investigate, but since it was not the purpose of the questions in this questionnaire the results are difficult to use. The questions had perhaps benefited from a reformulation to better suit the situation.

5.1.2 Comparison of Questionnaire Results from the Three Office Types

Another part of the result was to compare the questionnaire results from the three office types, both regarding the answers as well as a statistical comparison. Generally, the respondents from the wooden offices answered on the lower part of the scale for question number 6 to 25 (see appendix A). From the results of question number 26 (see appendix A) it can be understood that a fourth of the respondents answered "Nothing, I am not disturbed by any particular sound in the office", while only a tenth of the respondents in both the combined- and concrete offices choose this alternative. This might indicate that wooden offices do not have as many specific sources causing noise disturbances as the other office types, which can lead to a better overall acoustic environment. Although it should be kept in mind that the total number of answers are much lower for the wooden offices than the other types (43 from wooden offices, 122 from concrete and 164 from Trafikverket).

The result of question number 26 shows that impact noise is a more common source of disturbance in the wooden offices, but again questions number 6 and 7 say the opposite. Something else that is noticeable when looking at the comparison for

question number 26 is that traffic noise is more commonly chosen by respondents in concrete offices. This might be explained by the close proximity to a bigger road for two out of the three concrete offices. For both the combined- and concrete offices the alternatives regarding colleagues talking in different forms are more frequently chosen compared to the answers from the wooden offices. A reason for this could be the activity-based layout, which the majority of the respondents are located in. This can also be seen in questions 29 and 30 (see appendix A) where the respondents in the combined- and concrete offices perceive their concentration to be more disturbed as well as believe that they can not have confidential conversations to the same degree as respondents in wooden offices.

It was understood from the written answers by respondents located at AFRYs office in Stockholm that they had ongoing construction work. This might have influenced the answers since a lot of respondents mentioned that they were disturbed by construction noise. It is important to keep this in mind since it can give a false picture of how the acoustic environment is perceived by the respondents in normal conditions.

In the responses from the concrete offices an interesting comment popped up in some of the answers. Women in the age above 40 are more likely to experience the risk of disturbing others when talking on the phone (or Teams etc.) to be a problem of the acoustic environment as well. This is of course also an important aspect when it comes to how the sound environment is perceived in the office. It can be equally disturbing to the concentration to not feel comfortable speaking as needed, and ties up well with that many offices nowadays are too quiet. If one does not feel comfortable in the acoustic environment it will affect the general perception of it negatively. It is also interesting that it is only women above a certain age that commented on this.

The gender distribution among the respondents is equally divided between females and males. The comments above proves why it is of great value to include a variety of people when doing a survey. The age distribution among the respondents varies a lot, from younger to older respondents. This is also good since it gives a general picture of how the acoustic environment is perceived for all of the different age groups.

5.1.3 Correlation to Collected Available Measurement Data

The last part of the result was to investigate collected available measurement data and try to correlate it with the questionnaire results. Generally, it was hard to see any connections between what the respondents answered and the measured acoustic properties in the different offices, although a few possible correlations are found. For airborne sound insulation no clear relationships were found that could be applied for all offices to compare the acoustic environment. Regarding impact noise all offices have low mean values in the questionnaire. This correlates somewhat to the measurement data since a lot of the measured levels are better than the requirements. When it comes to the reverberation time the results from the questionnaire does not

correlate to the measurement data. Lastly, the installation noise data correlates to the questionnaire responses in the way that they are better than the requirements and very few are disturbed by it. Still, the ventilation was perceived to be a problem in meeting rooms in some of the wooden offices.

It was hard to know how to compile the data from all the different measurement reports since they contained different kinds of information and were structured in different ways. Another method of handling it might have benefited the thesis and made it easier to draw conclusions or be able to calculate correlations between the questionnaire and the measurement reports.

5.1.4 Overall Reflection on the Result

When looking at the result as a whole it was noted that there are some differences found between the different offices types, but if these differences are due to the type of construction or caused by other factors can not be said with certainty without doing further investigations and statistical analyses of the results. It was shown though that what people working in offices are most disturbed by are their colleagues, and this is mostly related to the office layout, general workplace culture and personal preferences. Difficulties in correlating the questionnaire results to the collected available measurement data points towards that no general conclusions can be drawn from the gathered results for all existing wooden offices. The results of the thesis shows how some aspects of the acoustic environment are perceived by the respondents in wooden offices, but it is not possible to apply the results with certainty for all wooden offices in general.

An overall observation for all the offices based on the results is that the acoustic environment in general is perceived to be good, but that there are certain areas that the employees feels needs improvement. Positively for the new mindset of building more sustainable, and therefore transitioning to building more in wood, is that in this study the results for the wooden offices turned out to be somewhat better in general than the results for the concrete offices. More things than just the acoustic environment might play a roll in this, such as the positive social effects wood has on human beings. The acoustics is only one part in the overall impression of a working environment, and even though this study only investigated the acoustics there is no easy way to know if the responses are truly distinguished from other senses and feelings.

5.2 Method Discussion

Three main methods was used to obtain the results of this thesis; a literature study, a questionnaire survey and an analysis of collected available measurement data. However, it is worth questioning if these methods turned out to be the most favourable for the problem formulation. It is also of interest to reflect on the choice of office buildings used in the study.

5.2.1 Choice of Offices

In the thesis work a total of eight offices was studied, four wooden offices, three concrete offices and one combination office. The intention from the beginning was to have six wooden offices and four concrete office as part of the study, but difficulties with contacting the offices resulted in that one wooden and one concrete office had to be disregarded since they did not respond. The choice of wooden offices for the study was also limited by the number of existing buildings in use, since the shift in mindset to build larger office buildings in wood instead of concrete is recent. When sending out the questionnaire it was believed that the total number of wooden offices in the study was five, but soon after it was understood from the comments in the responses that Trafikverkets headquarter in Borlänge is only partly constructed in wood. This was a big surprise which required some rethinking of how to manage the results, especially since half of all responses to the questionnaire comes from employees at Trafikverket. Due to this it was decided to not exclude the results completely, but instead add it to the study as a "combined office". This put light on the importance of a sufficient background check of the offices before sending out a request to distribute a questionnaire.

5.2.2 Questionnaire Design and Distribution

The main method used for the thesis is the questionnaire survey to investigate the third question in the problem formulation "*How is the acoustic environment in wooden offices perceived by the people working there?*". Creating a questionnaire without any previous experiences meant that it was challenging to create questions that would result in useful information. The overall result of the questionnaire survey could be of use, but some questions turned out to be unnecessary since they do not add any additional information, e.g. questions number 4 or 5 (see appendix A). Some questions could also have benefited from being more particular in the formulation to give answers that are easier to interpret, e.g. questions number 22 to 25 (see appendix A). One thing that was very clear when processing the answers is that a fifth option to question number 1 was needed, since a big part of the respondents are working in activity-based layouts. It would have been good to be able to separate the answers from them with those who work in a more classical open plan office layout, since they might have different experiences of the acoustic environment. Another design aspect that might have had big impact on the results is the scale in questions 6 to 25 and 28 to 30 (see appendix A). From the literature study it was seen that previous surveys regarding acoustic environment often uses a scale of 0 to 10, where 5 is neutral, which is what was used here as well. Although from the results it is noted that the answers are very spread out and hard to interpret due to it, and it can therefore be discussed whether or not it would have been better to use a 5-grade scale, as the standard *Acoustic quality of open office space (ISO 22955:2021, IDT)* suggests, to get more clear results.

The distribution of the questionnaire was much more difficult than expected. The main problem was to get in contact with the right people. It was believed at the

beginning that it was the property owners that should be contacted and asked to get permission and help to distribute the questionnaire. The response from the property owners was to instead contact the companies directly, which was done. For some companies this worked fine, for others it was hard to find the right person to speak to. Eventually it was understood that the best person to get in touch with was someone responsible for communication or human resources at the company. The whole process of getting the questionnaire distributed became very time consuming, and it was understood that contact should have been made already at the start of the thesis work and not one and a half month in. Once the questionnaire was distributed the response rate from the different offices varied a lot. Some offices sent the questionnaire directly to the employees via email, while others posted it in a news channel for the employees to see. It was noticed that the direct emailing gave a better response rate, but overall it is believed to be a big fall out of respondents at each office compared to the total number of employees (even though this number is unknown). From the people answering the questionnaire the fall out on particular questions is very low which is a good sign that the questionnaire design worked. It was chosen to do the questionnaire in English instead of Swedish to avoid misinterpretation of the answers when analysing the results. This decision might have affected the response rate since some people may not be comfortable using English, although it was explained that questions requiring writing could be answered in Swedish as well.

Using a questionnaire to investigate how workers in wooden and concrete offices perceive their acoustic environment was on the whole a suitable method, but it would probably have been beneficial to complement it with additional methods. For example, interviews could have been used to get a more in depth understanding of the responses. One of the best ways to understand the answers of the questionnaire are to read the comments left by some of the respondents, but to ask them to comment on every question would not have been reasonable either. Interviews could have been combined with study visits, like the one in Nodi, since it gave a slightly better understanding of the building and how the people in it experience the acoustics of it.

5.2.3 Collected Available Measurement Data

The second major part of the method was the processing of already existing measurement data on the investigated buildings. During the process three main problems was encountered. The first was to get a hold of the measurement data, where for some offices it was hard to know who to ask and for others hard to find the reports in the archive. The second problem identified was the different amount of data on the buildings and which parameters that existed for which office. Some office had very little data, making it harder to compare the results to both the other buildings and the questionnaire responses. The third problem was to find a way to correlate the measurement data to the questionnaire results. It would probably have been more effective to receive the reports before designing the questionnaire, to create the survey based on information from the collected available measurements. This could have given even more useful answers that would be more comparable to the

data.

Using collected available measurement data as a method may in retrospect not have been the best choice. Since the available data differed so much between the buildings, and for some buildings and parameters did not exist at all, it is hard to see patterns or make any bigger conclusions linked to office type which was desired to do. Generally it is also hard to correlate the measurement data to the results from the questionnaire in this thesis, especially since improvements have been done to most of the measured spaces after the reports were written. It is therefore not known what values the offices have at present moment. Due to this it would have been good to do some basic measurements of the offices as they are now. Doing extra measurements could have improved the understanding of the acoustic environment in the offices and made it possible to find clearer correlations and results.

5.2.4 Literature Study

Regarding the literature study it was quickly noticed that there is not a lot of published research on acoustics in wooden offices. Research on acoustics in wooden buildings have up till now mainly been made on residential buildings, and while some aspects of the sound are similar, others do not translate well to offices (e.g. sleep disturbance). Literature on concrete buildings on the other hand was a lot easier to find since it have been the more conventional way of building offices.

5.3 Ethical Aspects

Since the majority of people spend a lot of time in a working environment it becomes crucial to acknowledge the acoustic environment within the office space. According to the theory office noise can create disturbance, annoyance, affect productivity as well as the employees mental health. Thereby it becomes essential to minimize noise within the office space so societal aspects such as health and well-being are not compromised.

When conducting a questionnaire survey it is of big importance to consider whether or not to keep the respondents anonymous. The survey conducted for this report collects no sensitive personal information or information that can directly identify a certain respondent. The information collected that possibly could contribute to identifying a specific person when putting several pieces of information together is the questions about which office the respondent work in, what gender they identify as and their age. The questions in the questionnaire chapter "General information about your workstation at the office" could also possible be used to identify a specific person. Although, none of the information presented in this report can directly or indirectly be used to identify a specific respondent since only a compilation of all the answers are presented. It is also important to remember that no questions in the questionnaire was compulsory to answer and the respondent could chose to skip those who they did not feel comfortable to answer, which was clearly communicated

in the introduction letter. Participation in the survey was voluntary. All responses to the questionnaire is deleted at the end of the thesis work.

5.4 Further studies

The area of acoustic environment in wooden offices is relatively new and few published reports exist on the subject. As the thesis work progressed it became clear that the subject is much wider than what could fit within the scope of this report. Here follows a list on topics that could be interesting to investigate further in the future:

- The results showed that the subject would have benefited from a deeper investigation of a smaller group of offices. It is therefore suggested to combine a more focused questionnaire survey, with interviews and study visits at the investigated offices. To compliment even further, new measurements of specific spaces could be made based on the answers from the survey and interviews, as well as good and bad areas identified during the study visit.
- From the questionnaire results it was noticed that the answers from the activity-based offices had a somewhat different content than the others. The sounds created by colleagues in the workspace were perceived as more disturbing in this type of office layout, and from the comments it could be noticed that the people in general identified more problem areas with regards to the acoustic environment. It would be interesting to make a study about the acoustic environment inside activity-based offices, regardless of the building construction and consider the effect of social and psychological values in combination with the acoustics.
- In this study only pure wooden and concrete constructions was investigated, with the exception of Trafikverkets headquarters in Borlänge which is a mixture of old and new buildings. In a future study it could be of interest to also investigate hybrid constructions that have construction elements of both wood and concrete or steel.
- Something that was intended to be part of the investigation in this thesis was the effect of the COVID-19 pandemic on the acoustic environment in offices, but since the wooden offices was not in use before the pandemic it was not really feasible. The topic though is still interesting and could be investigated in offices that has been around for a reasonable amount of time before the COVID-19 pandemic as well.
- Due to the wide spread of things to investigate within the subject of *Acoustic environment in wooden offices*, a future study would benefit from investigating a smaller set of parameters/aspects of the acoustic environment in a larger number of offices to be able to find general results and conclusions. For example, it could be interesting to investigate only parameters regarding building

acoustics, or only parameters regarding room acoustics or perhaps only regarding talking colleagues. If several investigations like this are made, they can later be compiled to find the overall picture of the acoustic environment in wooden offices.

6

Conclusion

This thesis aimed to investigate the acoustic environment in wooden offices to identify differences between offices in wooden buildings compared to concrete buildings. To do so, three problem formulations were examined using a study of published literature, a questionnaire survey and collected available measurement data. The results are following:

- *What are the acoustic differences between wooden- and concrete offices?*

The acoustic differences in wooden and concrete buildings are mainly due to their different weight. Wooden buildings are lightweight constructions while concrete buildings are heavyweight constructions. From the literature study it is learnt that impact noise and low frequency noise is a common problem in wooden constructions, but not as common in concrete constructions. Regarding high frequencies, the wooden buildings usually have higher damping than concrete buildings. One of the reasons why it is harder to design the acoustic environment in a wooden building compared to a concrete building is the lack of prediction models developed and adapted to lightweight buildings. Since most larger buildings in the past has been made of concrete the existing prediction models for concrete are very accurate. For wooden buildings, it has not been possible to collect enough knowledge from existing projects to develop the experience. From the results of the questionnaire study and analysis of collected available measurement data in this thesis, some differences between the wooden and concrete office was found, but if they are connected to construction type or caused by some other factors needs to be further investigated.

- *What is the correlation between the perceived acoustic qualities and the measured acoustic parameters in a wooden office?*

Between the questionnaire results and the collected available measurement data analysed in this report, no clear correlations are found. The data from the collected available measurements are inconsistent for the different offices investigated, and the questionnaire results are only indicating how the acoustic environment is perceived in general in the studied offices since it is unknown if the group of respondents are representative for the whole population. The overlap between the measurement data and the questions in the survey is not big enough to allow comparison between them, and no general patterns could be observed. There is also a need for more measurement data in order to

answer the question.

- *How is the acoustic environment in wooden offices perceived by the people working there?*

The acoustic environment in the wooden offices in this study is perceived in general as good by the people working there. The main disturbances in the wooden offices in the study are sounds from colleagues talking on the phone (including Teams, Zoom etc.) and colleagues talking with each other around your workstation. Impact noise was also rated by a third of the respondents in the questionnaire as one of the sources causing disturbance, but around a fourth of the respondents were not disturbed by anything in particular. The overall responses in the questionnaire shows a positive view on the acoustic environment in wooden offices.

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A

Appendix 1

The questionnaire sent to the wooden offices in the survey is presented here in full. In figure A.1 the introduction letter and question about which office the respondent works in is shown for the questionnaire sent to the concrete offices. The rest of the questionnaire for the concrete offices is the same as for the wooden offices.

Acoustic Environment in Wooden Offices

Best respondent,

we are two students from the master's program Sound and Vibration at Chalmers University of Technology. Currently we are writing our master's thesis on the subject of *Acoustic Environment in Wooden Offices*, in collaboration with Efterklang part of Afry. As part of our work we are conducting a survey aimed towards people working in wooden and concrete offices. You are a part of the selected group of people working in a concrete office. The questionnaire you are about to answer is designed to collect information about your working environment and what effects sound has on it. It also collects information about how you perceive the acoustic environment in your office. Your answer is important and will greatly help us in our work to investigate the acoustic environment in wooden offices.

The questionnaire is divided into different areas of interest, and you will be asked to answer one at a time. No questions are compulsory to answer, but we kindly ask you to answer as many of them as you feel comfortable doing. Some questions will ask you to write an answer in your own words. These questions you are allowed to answer in Swedish if you prefer that. It is possible to move freely in the questionnaire until you have submitted it. Your answers will remain strictly confidential and no email addresses or names will be collected. Participation in the study is voluntary. The questionnaire contains 38 questions and the estimated time required to complete it is **15 minutes**. It will be possible to answer the survey until **2023-05-04**.

Thank you for your participation in the study, it will be of huge help to our thesis work!

Kind regards,
Emilia Nobelius & Isabella Ståhl

Contact: nobelius@chalmers.se or stahli@chalmers.se

The office building

The following question is asked to identify differences regarding acoustic environment in different types of concrete constructions.

1. In which building is your office located?

Markera endast en oval.

- AFRY, Göteborg
- AFRY, Malmö
- AFRY, Stockholm
- Johanneberg Science Park, Göteborg
- Don't know

Figure A.1: The introduction letter and question about office belonging in the questionnaire sent to the concrete offices.

Acoustic Environment in Wooden Offices

Best respondent,

we are two students from the master's program Sound and Vibration at Chalmers University of Technology. Currently we are writing our master's thesis on the subject of *Acoustic Environment in Wooden Offices*, in collaboration with Efterklang part of Afry. As part of our work we are conducting a survey aimed towards people working in wooden and concrete offices. You are a part of the selected group of people working in a wooden office. The questionnaire you are about to answer is designed to collect information about your working environment and what effects sound has on it. It also collects information about how you perceive the acoustic environment in your office. Your answer is important and will greatly help us in our work to investigate the acoustic environment in wooden offices.

The questionnaire is divided into different areas of interest, and you will be asked to answer one at a time. No questions are compulsory to answer, but we kindly ask you to answer as many of them as you feel comfortable doing. Some questions will ask you to write an answer in your own words. These questions you are allowed to answer in Swedish if you prefer that. It is possible to move freely in the questionnaire until you have submitted it. Your answers will remain strictly confidential and no email addresses or names will be collected. Participation in the study is voluntary. The questionnaire contains 38 questions and the estimated time required to complete it is **15 minutes**. It will be possible to answer the survey until **2023-04-21**.

Thank you for your participation in the study, it will be of huge help to our thesis work!

Kind regards,

Emilia Nobelius & Isabella Ståhl

Contact: nobelius@chalmers.se or stahli@chalmers.se

The office building

The following question is asked to identify differences regarding acoustic environment in different types of wooden constructions.

1. In which building is your office located?

Markera endast en oval.

- A Working Lab (AWL), Göteborg
- Magasin X, Uppsala
- Nodi, Nya Hovås
- Trafikverket, Borlänge
- Trikåfabriken, Stockholm
- Don't know

General information about your workstation at the office

The following questions relate to your current workstation at the office (the physical place, not the company). You assess questions 1, 3 and 5 by marking the answer that corresponds best to your workstation situation. You assess questions 2 and 4 by choosing the interval that corresponds best to your situation.

2. 1. Is your workstation currently located in an open plan office or in a private office room?

Markera endast en oval.

- Open plan office *Fortsätt till fråga 9*
- Private office room *Fortsätt till fråga 9*
- Working from home only
- Don't know *Fortsätt till fråga 9*
- Övrigt: _____

3. 2. How many people work in the space/room in which your workstation is currently located?

Markera endast en oval.

- Less than 2 *Fortsätt till fråga 9*
- 2-5 *Fortsätt till fråga 9*
- 6-10 *Fortsätt till fråga 9*
- 11-20 *Fortsätt till fråga 9*
- 21-30 *Fortsätt till fråga 9*
- 31-40 *Fortsätt till fråga 9*
- More than 40 *Fortsätt till fråga 9*
- Don't know *Fortsätt till fråga 9*

4. 3. At what floor in the building is your workstation located?

Markera endast en oval.

- Top floor
- Ground level
- Other
- Don't know

5. 4. For how many years have you worked in the office building in which your workstation is currently located? (*mark the option you consider to be closest to the number of years*)

Markera endast en oval.

- Less than 1 year *Fortsätt till fråga 9*
- 1-2 years *Fortsätt till fråga 9*
- 3-5 years *Fortsätt till fråga 9*
- 6-10 years *Fortsätt till fråga 9*
- More than 10 years *Fortsätt till fråga 9*
- Don't know *Fortsätt till fråga 9*

6. 5. Have your workstation always been of the same type at the office in which your workstation is currently located?

Markera endast en oval.

- Yes, always open plan office *Fortsätt till fråga 9*
- Yes, always private office room *Fortsätt till fråga 9*
- No/Other *Fortsätt till fråga 7*
- Don't know *Fortsätt till fråga 9*

You answered "**No/Other**" to the previous question "*Have your workstation always been of the same type at the office in which your workstation is currently located?*"

This is a follow up to question number 5.

7. 5.1 In what way has your workstation changed?

26. 23. How often do you feel disturbed by sounds from areas outside of the office (e.g. corridors, lunch room, other departments)?

Markera endast en oval.

0 1 2 3 4 5 6 7 8 9 10

Never Constantly

27. 24. If you work in a smaller room (e.g. group room, meeting room, private office room), are you in general disturbed by sounds through the wall from adjacent rooms?

Markera endast en oval.

0 1 2 3 4 5 6 7 8 9 10

Not Totally

28. 25. If you work in a smaller room (e.g. group room, meeting room, private office room), how often do you feel disturbed by sounds through the walls from adjacent rooms?

Markera endast en oval.

0 1 2 3 4 5 6 7 8 9 10

Never Constantly

Assesing the acoustic environment of your work area, *continued*

The following questions relate to what type of acoustic disturbance you experience. You assess the questions by ticking the boxes corresponding best to your experience. Choose one or more options for each question.

29. 26. Which sound/sounds do you feel disturbed by at your workstation? *Choose one or more options.*

Markera alla som gäller.

- Impact noise (sounds created by impacts on the floor, e.g. footsteps)
- Ventilation
- Installation noise (e.g. elevators, water flow in pipes)
- Machines in the office (e.g. printer, computers, phones ringing)
- Traffic noise from outside of the office building
- Colleagues talking on the phone (including Teams, Zoom etc.)
- Colleagues talking with each other around your workstation
- Noise from people working (e.g. typing on keyboards, shuffling papers)
- Noise from other areas outside the office (e.g. corridors, lunch room, other departments)
- Sounds through the walls from adjacent rooms (when working in e.g. group room, meeting room, private office room)
- Nothing, I am not disturbed by any particular sound in the office
- Don't know
- Övrigt: _____

30. 27. During which work task/tasks do you feel disturbed by any of the sounds mentioned in the previous question? *Choose one or more options.*

Markera alla som gäller.

- Reading
- Writing
- Talking on the phone
- Conversating with colleagues
- Meetings
- Computer work (e.g. calculations, working in different programs)
- Nothing, I am not disturbed during any particular task
- Don't know
- Övrigt: _____

34. 31. In general, is there a certain area/areas in your office in which you perceive the acoustic environment to have a different quality (e.g. extra good or extra disturbing)?

Markera endast en oval.

- Yes *Fortsätt till fråga 35*
- No *Fortsätt till fråga 38*
- Don't know *Fortsätt till fråga 38*

You answered "**Yes**" to the previous question "*In general, is there a certain area/areas in your office in which you perceive the acoustic environment to have a different quality (e.g. extra good or extra disturbing)*"?

This is a follow up to question number 31.

35. 31.1 In which area/areas do you perceive the acoustic environment to have a different quality?

36. 31.2 How do you perceive the acoustic environment to have a different quality?

Markera endast en oval.

- Extra good
- Extra disturbing
- Don't know
- Övrigt: _____

37. 31.3 Why do you perceive the acoustic environment to have a different quality in this area/areas?
-

Effects of the COVID-19 pandemic on workplace

Following questions relate to how the COVID-19 pandemic has affected your work situation. You assess each question by marking the answer that corresponds best to your work situation.

38. 32. In general, how many days during a week do you work in the office?

Markera endast en oval.

0 1 2 3 4 5 6 7

39. 33. In general, have the number of days that you work in the office during a week changed, compared to before the COVID-19 pandemic?

Markera endast en oval.

- Yes, I work in the office MORE days now compared to before
Fortsätt till fråga 43
- Yes, I work in the office LESS days now compared to before
Fortsätt till fråga 43
- No, I work the same number of days in the office now as before
Fortsätt till fråga 43
- Don't know *Fortsätt till fråga 43*

40. 34. In general, do you experience a difference in the acoustic environment at the office now, compared to before the COVID-19 pandemic?

Markera endast en oval.

- Yes *Fortsätt till fråga 41*
- No *Fortsätt till fråga 43*
- Don't know *Fortsätt till fråga 43*

You have answered "**Yes**" to the previous question "*In general, do you experience a difference in the acoustic environment at the office now, compared to before the COVID-19 pandemic?*"

This is a follow up to question number 34.

41. 34.1 In what way do you experience the acoustic environment to be different?

42. 34.2 Why do you experience this difference?

General information about you

Following questions relate to you. You assess each question by choosing the option most suitable for you.

43. 35. What gender do you identify as?

Markera endast en oval.

- Female *Fortsätt till fråga 47*
- Male *Fortsätt till fråga 47*
- Other *Fortsätt till fråga 47*
- Prefer not to say *Fortsätt till fråga 47*

44. 36. How old are you?

Markera endast en oval.

- Younger than 18 *Fortsätt till fråga 47*
- 18-25 *Fortsätt till fråga 47*
- 26-35 *Fortsätt till fråga 47*
- 36-45 *Fortsätt till fråga 47*
- 46-55 *Fortsätt till fråga 47*
- 56-65 *Fortsätt till fråga 47*
- 65+ *Fortsätt till fråga 47*

45. 37. Do you consider yourself to have normal hearing?

Markera endast en oval.

- Yes *Fortsätt till fråga 47*
- No *Fortsätt till fråga 47*
- Don't know *Fortsätt till fråga 47*

46. 38. Do you consider yourself extra sensitive to noise?

Markera endast en oval.

- Yes *Fortsätt till fråga 47*
- No *Fortsätt till fråga 47*
- Don't know *Fortsätt till fråga 47*

Questionnaire completed

Thank you for your participation in our study! Your answers are valuable and of great help for our investigation of acoustic environment in wooden offices. The answers you have given are strictly confidential and no email addresses or names are collected. Participation in the study is voluntary. It will be possible to submit the answers until **2023-04-21**.

If you have any questions regarding the questionnaire, feel free to contact us at **nobelius@chalmers.se** or **stahli@chalmers.se**.

47. Do you have any additional comments you would like to add?

Det här innehållet har varken skapats eller godkänts av Google.

Google Formulär

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