BUILDING ACOUSTICS IN HOMES

A Literature Study Based on Three Common Sound Environments

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Bachelor's Dissertation
at Engineering Acoustics

DEPARTMENT OF CONSTRUCTION SCIENCES

DIVISION OF ENGINEERING ACOUSTICS

ISRN LUTVDG/TVBA--16/6002--SE (1-33) | ISSN 0281-8477

BACHELOR'S DISSERTATION

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A Literature Study Based on Three Common Sound Environments

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Abstract

The aim for this thesis is to find out what aspects are important to create a good sound environment at home. In order to do this three different sound environments has been studied in the literature review: hospitals, schools/pre-schools and offices. Important acoustical parameters was picked out and a method for evaluating the sound environment at home was carried out. The main subject was to find out what parameters had importance for building acoustics, but since there in some cases was found that other parameters could have great importance, both acoustic and non-acoustic parameters were studied.

The main reason to acknowledge building acoustics is because of public health. Studies has shown that being exposed to long term high noises can cause both physiological and psychological diseases which in turn puts a higher work load on society in terms of increased need of health care.

A good sound environment at home can be accomplished with a planning that gives the possibility for privacy, and is suited for social relations. The living area can be open plan if considerations has been taken to the room geometry to minimize room reflections, and kept reverberation times short. Kitchen wares should be kept at a minimum sound level, especially if having an open-plan solution between kitchen and other living areas.

Sammanfattning

Målet med detta kandidatarbete är att undersöka vad som är viktigt att tänka på om man vill skapa en god ljudmiljö i hemmet. Eftersom det i dagsläget inte finns särskilt mycket forskning om akustik i hemmet har denna litteraturstudie fokuserat på tre andra vanliga typer av lokaler nämligen sjukhus, skolor/förskolor och kontor. Genom att hitta viktiga akustiska parametrar inom dessa typer av lokaler, där det finns mer forskning tillgänglig, har en metod för att utvärdera ljudmiljön i hemmet skapats. Huvudmålet var att utreda vad som var viktigt ur ett byggnadsakustiskt perspektiv men eftersom det framkom att många andra aspekter kan spela stor roll för hur den slutliga ljudmiljön uppfattas diskuterades även andra aspekter.

Den huvudsakliga anledningen att bry sig om byggnadsakustik är folkhälsan. Flera studier har visat att långvarig exponering för höga ljudnivåer kan orsaka båda fysiska och psykiska sjukdomar. Detta medför i sin tur ökat behov av sjukvård.

En god ljudmiljö i hemmet kan uppnås med en planlösning som ger möjlighet till avskildhet men också har rum anpassade för umgänge. Rum anpassade för umgänge kan ha en öppen planlösning om man tar hänsyn till rummets geometri för att minimera reflektioner och få en kort efterklangstid. Ljudnivån från vitvaror ska hållas så låg som möjligt, speciellt om man har en öppen planlösning mellan kök och vardagsrum.

Acknowledgement

This bachelor's thesis has been carried out at the Division of Engineering Acoustics at the Institute of Technology at Lunds University, Sweden.

First of all I would like to express my deepest gratitude to my supervisor Delphine Bard. Your calm, and always positive ways has been a great support.

I wish to send a special thank you to my dear friend Anna for proofreading, and always being there for me.

Most of all I want to send all my love to my fantastic family who is always there for me, and to Johan who stays with me, for better and for worse.

Fanny Sandberg

Lund, June 2014

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1. Introduction

1.1 Background

In everyday life people are always under the influence of noise. Outdoors the noise is mainly generated from roads, railways, air traffic, and surrounding neighborhoods while indoors much of the noise is generated from ventilation systems, computers and kitchenware's. All these noises combined create the sound environment that we live in. Noise exposure is, in contrast to other environmental problems, an ongoing issue and the problems are particularly severe in cities. Cities contain the largest concentrations of people and is also where large hospitals, schools and workplaces are located. These are all places in need of a good acoustical environment to be fully functional. Today we spend almost 90 percent of our time indoors where many hard surfaces significantly amplify noise. This environment is very different from the one that our ears developed in for thousands of years.

1.2 Purpose

In this thesis three different sound environments have been studied: hospitals, schools/pre-schools and offices. This was done in order to find out which aspects are important to create a good sound environment and what impact a noisy environment can have on people. A summary of important acoustical and non-acoustical parameters for the three sound environments is presented, with the final goal to find acoustical parameters that could also be applied to room acoustics in homes.

1.3 Dissertation contents

1. The purpose and background of the thesis is presented.
2. Acoustical terms that are commonly used in building acoustics are closer explained.
3. Acoustics in hospital are being reviewed and important building strategies are suggested.
4. The school and pre-school are being reviewed from an acoustical perspective
5. Different type of offices are presented. The acoustical differences between the open-plan office and the cellular office are investigated.
6. A summary of important parameters for hospitals, schools and offices are suggested based on chapter three-five.
7. A method for evaluating the sound environment at home is suggested based on chapter six.
8. A discussion of the thesis is presented.

2. Important concepts

2.1 Sound and noise

Sound is defined as an oscillation in a medium or a material, most commonly propagated through air, resulting in a pressure variation (Nilsson et al, 2008). The outer ear captures the vibrations in the air and leads it into the inner ear where it is amplified (figure 1). The oscillations are transformed into nerve impulses that are recognized by the brain and result in sound.

FIGURE 1. THE EAR (LAKESIDE AUDIOLOGY, 2014).

Sound and noise are physically the same, however noise is defined as unwanted sound. What is unwanted sound is in many ways a subjective matter and up to the receiver to decide. To help define unwanted noise, WHO (1999) has made some measurements that can be used as guidelines. For example, the background noise should be at least 15 dB lower than speech to be able to get full speech intelligibility. Normal speech is around 60 dB, which means that a sound level of 75 dB can be disturbing and affect speech intelligibility. Speech intelligibility is a measure of how comprehensible speech is and can be affected by speech clarity as well as precision.

2.2 Sound pressure level (SPL)

Because the ear is sensitive to pressure variations in the air it is appropriate to describe sound by using the term sound pressure or acoustic pressure which has a linear scale with the unit Pascal (Nilsson et al, 2008). However, since the human ear can perceive sound pressures at both very low and very high levels this makes it inconvenient to use a linear scale. Therefore, another measurement known as the sound pressure level (SPL), or sound level, is used. This is a logarithmic measurement that gives the ratio to the standard reference level. The standard reference level is set at the sound pressure 20 µPa and the frequency 1000 Hz, which a healthy individual can barely hear. This is also known as the threshold for human hearing, which using the decibel-scale corresponds to 0 dB. The correspondence between sound pressure level and sound pressure is further explained in figure 2. Decreasing the SPL by 3 dB is equivalent to halving the sound pressure.

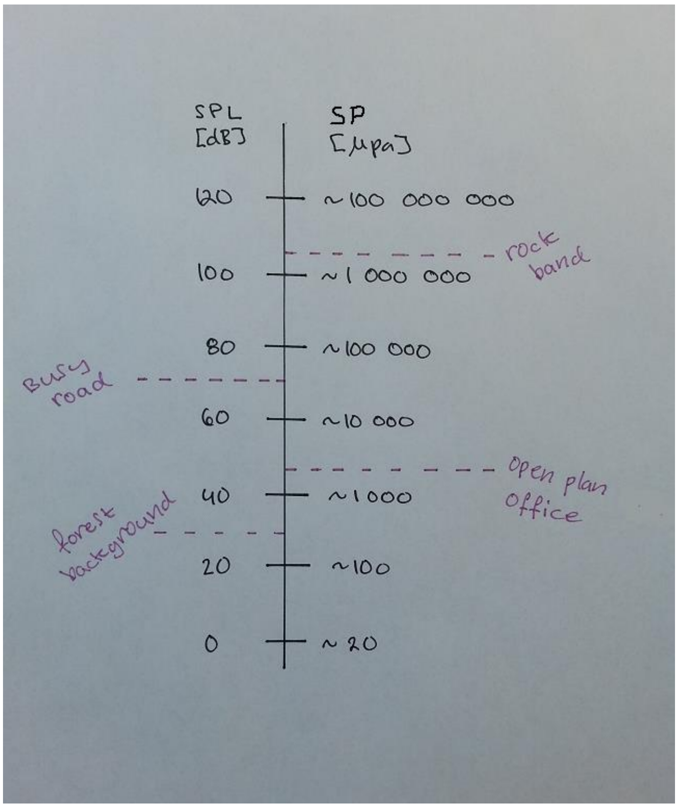


FIGURE 2. CORRESPONDENCE BETWEEN SOUND PRESSURE LEVEL (SPL) AND SOUND PRESSURE (SP).

2.3 Frequency

Whether a tone is perceived as a high pitch or a low pitch depends on how fast the pressure change is (Nilsson et al, 2008). The speed of the pressure change is measured in the number of periods per second and is called frequency. If the tone is high pitched the pressure change is fast, (a short wavelength) resulting in a high frequency. Similarly, for the low pitch tone the pressure change is slower, resulting in a lower frequency (figure 3). The human ear can hear frequencies between 20 Hz - 20 000 Hz.

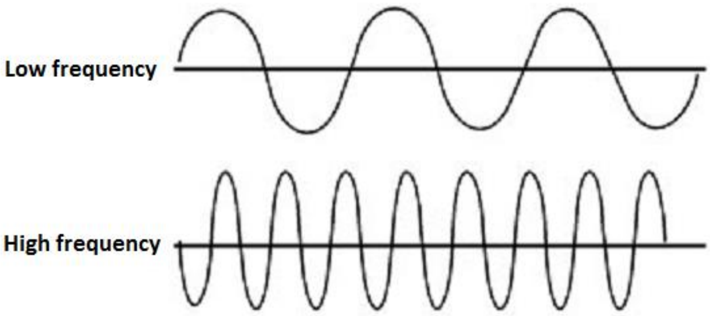


FIGURE 3. HIGH FREQUENCY AND LOW FREQUENCY (PRO TOOLS EXPERT, 2014).

2.4 Velocity of sound

It takes time for the sound to travel and the speed at which it travels depends on the material it is propagating in (Nilsson et al, 2008). The density of the material plays an important role since materials with higher densities propagate sound faster.

TABLE 1. VELOCITY OF SOUND IN AIR AND STEEL (NILSSON ET AL, 2008) AND (DAKOTA ULTRASONICS, 2014).

Medium	Long Velocity (m/s)	Shear Velocity (m/s)
Air	340	0
Steel	5900	3200

As shown in table 1 a solid material, like steel, carries the sound forward much faster than air. Also, in a solid material the sound wave can be both long and shear. This is an important factor to take under consideration when building a house. For example a steel beam running through an isolation material can create an audio bridge.

2.5 Phon-curves (or equal-loudness-curves)

The ear is more sensitive to some frequencies than others which makes the concept of frequency and sound pressure a little complicated (Nilsson et al, 2008). The physical sound pressure is not always the same as the perceived. A 100 Hz tone at 50 dB is not perceived as strong as a 1000 Hz tone at 50 dB. In order to compare different sound pressures at different frequencies a phon-curve, also called equal-loudness-curve, can be used (see figure 4). These curves give the perceived sound pressure level compared to the physical sound pressure level and frequency.

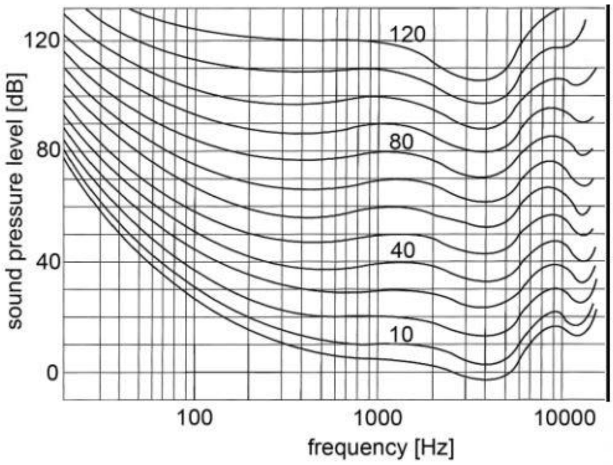


FIGURE 4. PHON-CURVE OR EQUAL-LOUDNESS CURVE (TEKNISK AKUSTIK, 2014).

2.6 Filters

As mentioned above the ear is more sensitive to some frequencies than others (Nilsson et al, 2008). To transform the objective measures to what we actually perceive, three filters (named A-, B- and C-filters) have been made that either strengthen or/and weaken the SPL at set frequencies. The filters are based on phon-curves 40, 60 and 80 respectively and the different curves are used at different SPL's. The A-weighted is the most commonly used curve and has a reduction of the lower frequencies that the ear is less sensitive to. The A-weighted curve is applicable when measuring low sound levels, around 30-40 dB, and at relatively high sound levels when the risk for damaging the hearing organ is severe. The risk for hearing damage is more likely at high frequencies. The C-weighted curve has very little reduction of the lower frequencies and the B-weighted is somewhere in between. The curves in figure 5 shows what sound pressures are filtered in A-, B- and C-filters.

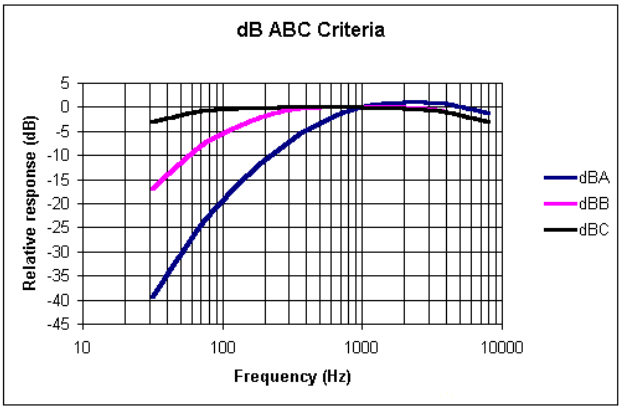


FIGURE 5. FILTERS (THE ENGINEERING TOOLBOX 2014).

2.7 Sound classifications

In Swedish standards and building regulations there are regulations for new constructions and additions/changes of existing buildings (Nilsson et al, 2008). In the Swedish Standards there are four different sound classifications, A to D where sound classification A corresponds to very good acoustic conditions and C is the minimum standard for Swedish housing. See table 2 for further description of class A-D**.**

TABLE 2. SOUND CLASSIFICATIONS (LINDROS, 2014).

Sound classification	Description
Class A	Very good acoustical conditions
Class B	Class B corresponds to better sound conditions than class C, although some people can still be disturbed by noise. This is the minimum standard if a "good living environment" is requested
Class C	This class corresponds to the minimum standard in Swedish constructions
Class D	This class is meant to be used if sound classification can't be achieved, for example during renovation.

2.8 Sound Reduction (R)

In Swedish housing there are regulations saying a certain amount of soundproofing has to be maintained, to diminish noise such as those from neighbors or roads (Nilsson et al, 2008). The sound insulation can be measured by using the term "sound reduction" (R). The sound reduction is defined as the relation between incoming sound effect against a wall and transmitted sound effect through the same wall. To be able to use this term in regulations weighted values are being used, the so called "weighted reduction value" (R_w). When measuring the weighted reduction value in a regular house (meaning not in a laboratory) there is no way to know if all sound actually transmits through the wall (no flanking transmission). This type of measurement is usually designated R'_w. A high R_w-value means that the sound insulation is good.

2.9 Impact noises (L)

When walking on or in some other way excite a building element (floors, walls, ceilings) a sound wave propagates through the building element, both longitudinal and sheer (Nilsson et al, 2008). These types of sound waves are called impact noises (L). They can be very intense and therefore make the sound travel far. In Swedish regulations the weighted impact noise (L_w) is used.

2.10 Flanking transmission

The isolating ability of a partition wall is not only dependent on its own characteristics. Sound can also transmit via the flanking walls (figure 6). This type of sound transmission is called flanking transmission and to minimize it well executed junctions are crucial. The flanking transmission is important to take into account to get the best sound reduction from the partition wall.

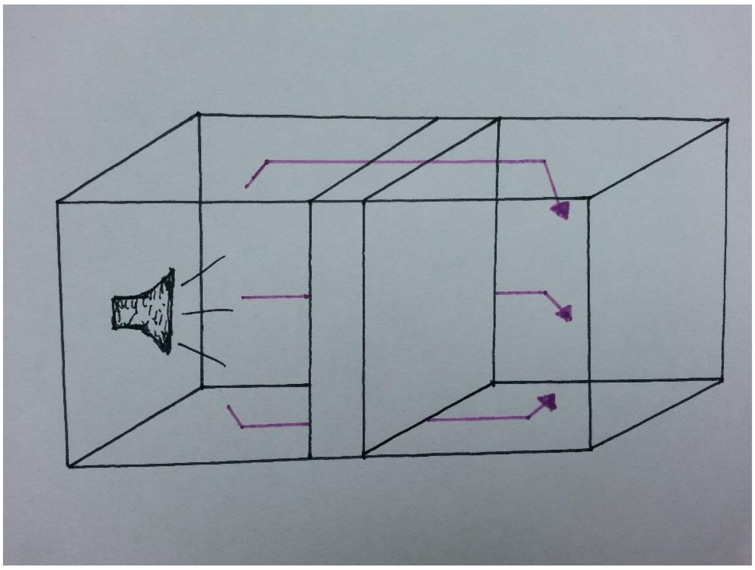


FIGURE 6. FLANKING TRANSMISSION. INSPIRED BY NILSSON ET AL. (2008).

2.11 Speech clarity

The sound that reaches the ear first is called direct sound (Ecophon, 2014b). Sound that reflects from other surfaces before it reaches the ear are included in the direct sound if it comes less than 50 ms after the initial direct sound (figure 7). Otherwise it will be perceived as disturbing. This phenomenon is called speech clarity (C_{50}) and compares the sound energy in early sound reflections with the later reflections (Lindros, 2014). A high value for C_{50} means the speech clarity is good.

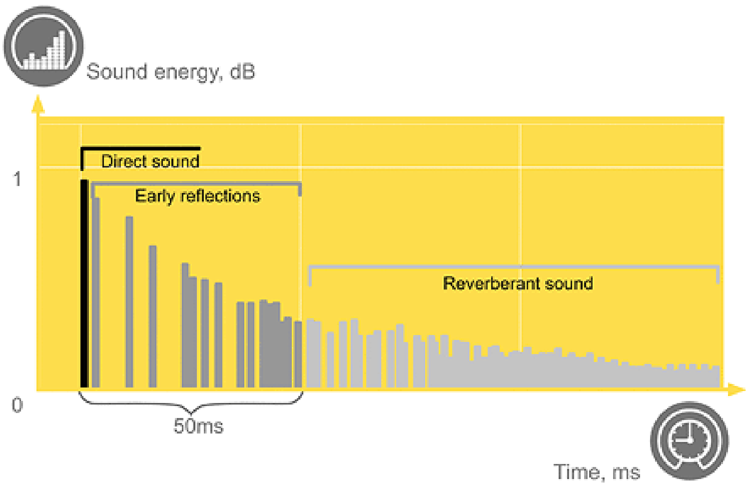


FIGURE 7. DIRECT SOUND, EARLY REFLECTIONS AND REVERBERANT SOUND (ECOPHON, 2014C). THE EARLY REFLECTIONS ARE INCLUDED IN THE DIRECT SOUND AND AMPLIFIES IT WHILE THE REVERBERANT SOUND WILL BE PERCEIVED AS DISTURBING.

2.12 Speech transmission index (STI)

Speech transmission index (STI) is a measure of speech transmission quality (Kaarlela-Tuomaala et al, 2009). The values varies between zero and one, where one corresponds to perfect speech transmission and zero is when there is no speech transmission (table 3). The STI relates well with subjective speech intelligibility, for example STI = 0.5 corresponds to roughly hearing 50 percent of syllables correctly.

TABLE 3. THE SUBJECTIVE SCALE OF HOW WELL SPEECH IS BEING HEARD AND CORRESPONDING STI-VALUES (LINDROS, 2014).

Subjective scale	STI value
Bad	0.0 – 0.3
Poor	0.3 – 0.45
Fair	0.45 – 0.6
Good	0.6 – 0.75
Excellent	0.75 – 1

2.13 Lombard effect

The Lombard effect is a phenomenon in which the speaker increase their vocal level in the presence of a loud background noise and make several vocal changes to improve the intelligibility of the speech (Vlaj, 2011). The main vocal changes that can happen apart from increase in vocal level is an increase in frequency and vowel duration. Also, the speaking rate can be reduced in a noisy environment.

2.14 Background noise

Background noises are sounds that are heard, but do not contain any valid information. Common background noises come from ventilation and roads but the background noise can also come from people talking from a distance etc. WHO's recommendations on sound levels in different environments are presented in table 4.

TABLE 4. WHO'S RECOMMENDATIONS ON SOUND LEVELS IN DIFFERENT ENVIRONMENTS (WHO, 2009).

Specific environment	Critical health effect(s)	L_{Aeq} [dB]	Time base [h]	L_{Amax} [dB]
Outdoor living area.	Serious annoyance, daytime and evening. Moderate annoyance daytime and evening.	55 50	16 16	- -
Dwelling, indoors. Inside bedrooms.	Speech intelligibility and moderate annoyance, daytime and evening. Sleep disturbance, night time.	35 30	16 8	 45
Outside bedrooms.	Sleep disturbance, window open (outdoor values).	45	8	60
School class rooms and pre-schools indoors.	Speech intelligibility, disturbance f information extraction, message communication.	35	During class	-
Pre-school bedrooms, indoors.	Sleep disturbance.	30	Sleeping time	45
School playground, outdoor.	Annoyance	55	During play	-
Hospital, ward rooms, indoors.	Sleep disturbance, nighttime. Sleep disturbance daytime and evenings.	30 30	8 16	40 -
Hospitals, treatment rooms, indoors.	Interference with rest of recovery.	As low as possible		
Industrial, commercial, shopping and traffic areas, indoors and outdoors.	Hearing impairment.	70	24	110

2.15 Masking

Noise affects the intelligibility when the noise level exceeds the speech level (Lindros, 2014). This is called masking, meaning that a sound gets lost due to other sounds. This can be both good and bad depending on if the sound being "masked" is important (like a warning alarm) or unimportant (like speech being unwillingly overheard).

2.16 Absorption

When a sound wave hits an object or material one part of the wave reflects and one part absorbs (Ecophon, 2014a). This can be described with equation 1 where Π_i is the incoming sound effect, Π_r is the reflecting sound effect and Π_a is the absorbed sound effect.

$$\Pi_i = \Pi_r + \Pi_a \qquad (1)$$

One part of the absorbed sound wave energy converts to heat energy and the rest transmits through the material or object. A materials sound absorbing properties are defined by the absorption coefficient (α) which gives the share of the sound effect that absorbs (see equation 2). The absorption coefficient ranges from 0 (total reflection) to 1 (total absorption).

$$\alpha = \frac{\Pi_a}{\Pi_i} \qquad (2)$$

The absorption area (A) gives a partial area, with $\alpha = 1$, that corresponds to the same absorption that the actual absorbing surface (S) will give (Nilsson et al, 2008). In conclusion: A is a theoretical area while S is the actual area that can be measured in a room. The absorption area can be described with equation 3 and an example follows bellow to further describe the concept.

$$A = \alpha \cdot S \qquad (3)$$

An absorbent, say a curtain, with $\alpha = 0.5$ and $S = 5$ m^2 will have an absorption area of $0.5 \cdot 5 = 2.5$ m^2. This means that 2.5 m^2 of an absorbent with $\alpha = 1$ (this corresponds to a 2.5 m^2 open window) will give the same absorption that 5 m^2 of the original absorbent (the curtain), see figure 8.

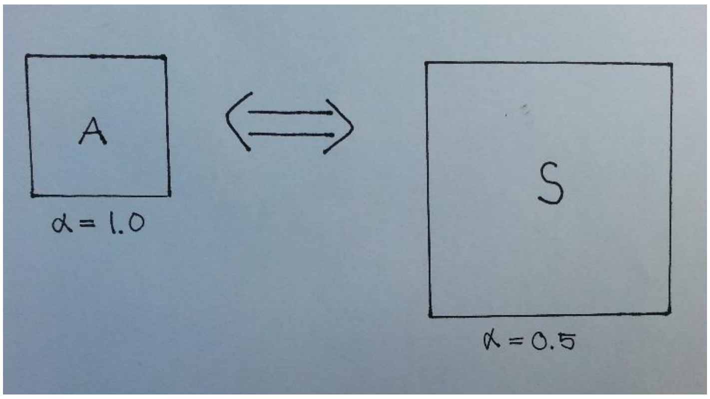


FIGURE 8. A REPRESENTS THE THEORETICAL ABSORPTION AREA AND S REPRESENTS THE ACTUAL ABSORBING AREA.

2.17 Reverberation time

It takes some time for a sound to disappear after the sound source has stopped (Nilsson et al, 2008). The rate of the decay of the sound depends on the geometry and the dampening in the room. The reverberation time (T_{60}) is defined as the time it takes for the sound energy to diminish by 60 dB.

$$T_{60} = K\frac{V}{A} \qquad (4)$$

Equation 4 explains how the reverberation time depends on the absorption area (A) and the volume of the room (V). The constant K is 0.16 s/m.

3. Hospital

When thinking about a hospital environment the first thing that comes to mind is that it should be a peaceful place for healing and resting, something that is not the case today (Ryherd et al, 2007). Modern hospitals have a lot of noise polluters such as staff, nearby patients, visitors, medical equipment, alarms, portable carts, ventilation, etc., and the acoustical environment is often not good enough at muting all the unwanted sounds. A common Swedish hospital room has linoleum tile flooring, gypsum walls, lay-in acoustical tile ceiling and a limited amount of furniture. There are many hard surfaces because they are easier to clean and hygiene is a main priority but this results in severe sound amplification since the sound cannot be fully absorbed (figure 9).

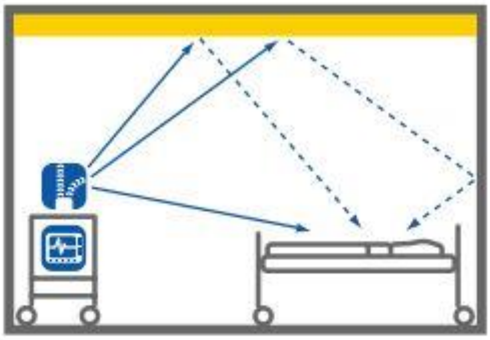


FIGURE 9. SOUND REFLECTIONS FROM HOSPITAL EQUIPMENT CAN BE AMPLIFIED IF THE ROOM HAS MANY HARD SURFACES WHERE SOUND CAN REFLECT (ECOPHON, (2011).

Hospital noise levels have increased over the last 50 years from average daytime levels at 57 dBA in 1960 to 72 dBA today. Night time levels have also increased from 42 dBA to 60 dBA (Ryherd et al, 2007).

3.1 Sleep

The body and mind react with different intensity to different SPL's during sleep (WHO, 2011). Sleep is a biological necessity and very important for basic human functions. The human organism recognizes, evaluates and reacts to environmental sounds even during sleep, which leads to an activation process that in turn leads to changes in sleep structure. These repetitive activations can reduce the restorative power of sleep. In a report about night noise in Europe issued by WHO (2009) it is established that average noise levels between 30-40 dB can disrupt sleep by body movements or awakening and that the perceived sleep-disturbance also increases at these levels. Levels over 55 dB are considered dangerous for public health and the risk of cardiovascular diseases are significant at these levels (table 5). Noise induced sleep disturbances are problematic because they lead to increases in the levels of stress hormones. Stress ulcers, increased dosage of pain medication and a lowered immune system are all symptoms of increased levels of stress hormones and are all risks with the noise induced sleep. Other known effects of noise are changes in blood flow, increased blood pressure and heart rate, which can all result in cardiovascular disease. These effects are important to take seriously, especially with heart patients who are more vulnerable to these kinds of changes. Sleep disturbance because of noise have also been shown to have a negative effect on creativity and risk-taking behavior (WHO, 2011). The risk of accidents also increases when an individual is disturbed during sleep.

TABLE 5. DATA COLLECTED FROM WHO SHOWING HOW AVERAGE NIGHT NOISE LEVELS CAN DISTURB SLEEP (WHO, 2009).

Average night noise level over a year	Health effects observed in the population
Up to 30 dB	No substantial effects are observed
30 to 40 dB	Effects on sleep: body movements, awakening, self-reported sleep disturbance. However, at this levels the effects are modest.
40 to 55 dB	Adverse health effects are observed among the exposed population. Many people have to adapt their lives to cope with noise at night.
Above 55 dB	The situation is considered increasingly dangerous for the public health. There is evidence that the risk of cardiovascular disease increases

3.2 Daytime noise

Daytime noises in hospitals are important to reduce for many different reasons. One is of course that patients need a calm environment for resting, not only in nighttime but also during the day. Another important aspect is for patient and staff to be able to communicate amongst each other, hear alarms or calls for help (Cisca, 2014). Privacy is also important in order for the patient to feel comfortable with sharing their medical history. Two-bed rooms are often an issue since, most of the time, there is just a single curtain between the beds. Noise also has adverse effects on cognitive performance and increases the numbers of error in work (WHO 1999). It has been shown that lower SPL's improved the wellbeing and reduced the stress level for the staff, which is important since they have high-pressure jobs with no margin for error (Cisca, 2014). Another benefit with lowered SPL's is that the patients rate the staff's attitudes and care as much better during lower acoustical periods (Juang et al, 2010).

Based on all facts on the negative effects from noise both daytime and nighttime in hospital environment WHO (1999) has recommended guidelines for background sound in ward rooms and treatment rooms at 30 dBA with peaks not to exceed 40 dBA. This contrasts with the measured levels and the fact that it is still rising is indeed a problem.

3.3 Design strategies

To consider what acoustical challenges that can occur during the building of a hospital it can be a good idea to have an acoustical engineer present during both the design process as well as during the construction and post-construction process (Cisca, 2014). This in order to cover all the acoustical challenges that can appear, dealing with everything from determining the construction site and solving constructional problems to choosing mechanical system designs and equipment. Depending on the site of the hospital, different noises can be necessary to shut out. The most common outdoor noises are related to air- or road traffic. Both existing and possible future highways and airports should be considered when determining the site for a new hospital. Sound levels in outdoor patient areas should be kept under and average of 50 dBA. This is possible even near noisy roads if noise barriers are used (figure 10). To keep road/air traffic noise out from the building a good façade insulation is of great importance (Fönster, fukt och innemiljö, 2014). However, the windows are often the weakest links when considering sound insulation of a façade, and to improve the sound insulation they need to be airtight. One way to accomplish this is to put in double seals around the edges of the window. To put in double glazed windows also improves the sound insulation. A sound insulated window can have up to 45 dB sound reduction.

FIGURE 10. NOISE BARRIER ALONG BUSY ROAD (BULLERSKÄRM, 2014).

When designing different types of rooms in the hospital the usage of the specific room is very central and important when deciding what acoustical measures will be needed (Lindros, 2014). Following procedure can be used to ensure a good acoustical environment in each type of room:

- Establish the usage of the room
- Decide what acoustical environment is desired
- Assure that the BBR's demands will be fulfilled
- Use geometrical conditions, surfaces, and absorbers in a modelling program
- Evaluate results
- Make measurements to ensure that the demands are fulfilled

The space planning has a significant impact on the acoustical environment (Cisca, 2014). In modern hospital constructions it has become popular to design with an open plan solution and large windows that let a lot of daylight into the building (Cambridge sound management, 2014). This is an acoustical challenge because sound can travel much longer if there are no walls to stop it. It is extremely important to keep speech intelligibility at a minimum range because of the patient's rights to confidentiality and the most efficient way to achieve this is by building single patient rooms. However this is not always possible due to lack of space. If single patient rooms is not possible due to lack of space, private meeting rooms for patients, relatives and health care employees can be an alternative (Cisca, 2014). These rooms provide privacy and improve communication between these groups. According to Lindros (2014) a normal sound environment is possible to achieve even in a four patient room if the patients are not in a poor condition. Patients that can keep a lower profile and that are quite mobile and independent do not get as disturbed by sharing rooms as patients in worse conditions. For example, if a patient makes noises because of pain or other emotions this noise can affect other patients negatively. Other patients can get worried because of noises like this which in turn can cause unnecessary stress.

One of the most stressful and annoying sound sources comes from corridors (Cisca, 2014). By decentralization of nurse's stations it is possible to minimize the corridor traffic. Nursing stations should also be closed off in intensive care units and postoperative areas.

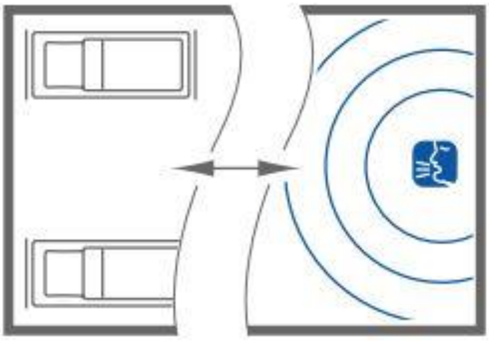


FIGURE 11. SEPARATE PATIENT ROOMS AND NURSES STATIONS (ECOPHON, 2011).

Selecting the right materials for ceilings, floors and walls can greatly improve the acoustic environment (Cisca, 2014). Acoustical ceiling tiles are in most cases possible to install. If an acoustical system with inner ceiling is not possible due to lack of space an alternative is to simply put sound absorbing panels directly onto the ceiling and upper walls as this also results in some noise reduction. Non-absorbing ceilings may allow sound to reflect or transmit from one space to another, possibly resulting in privacy breaches. The wall construction and surfaces are important to create a good acoustic environment. For best dampening performance all walls should be built from floor to underside of the next floor's structural deck and not just up to the inner walls (see figure 12). Doors and windows can have a significant negative impact on the walls insulating effect. This can be prevented with sound proofed doors and windows. Rubber floors are quite common in today's hospitals and result in less impact noise than for example vinyl composition tiles installed directly on concrete, which is also quite common. To minimize vibrations or noises caused by rolling equipment the use of thresholds and other discontinuities in the floor should be avoided. Finally, to absolutely get minimal speech transmissions between patient rooms and public areas, such as receptions and waiting rooms, sound masking systems should be installed (Cambridge sound management, 2014). With the subtle background noise the masking system transmits, the STI can be significantly lowered.

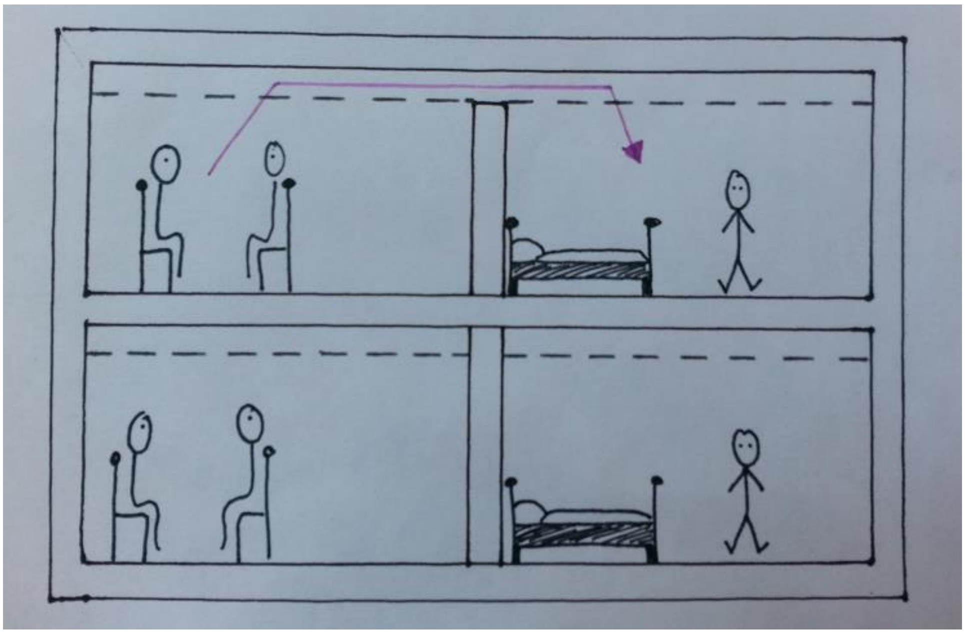


FIGURE 12. INNER WALLS THAT ARE NOT BUILT ALL THE WAY UP TO THE NEXT FLOORS STRUCTURAL DECK CAN CAUSE PRIVACY BREACHES. DASHED LINE REPRESENTS THE INNER CEILING.

4. School and pre-school

Schools and preschools are one of the largest work places in Sweden (Sjödin, 2012). Today the preschools are the dominating workplace with high noise levels among women and two out of three teachers/preschool teachers experience the sound environment as problematic every day.

Depending on the children's age the form of teaching can vary. During pre-school and the lower grades in school more playtime and free discussions are common but as the children get older, like in high school or at the university, more and more of the teaching is in the form of lectures and individual studying. This is important to consider when designing a school. The younger children needs more dampening of each other's voices while older students might be in more need of lowered background noises such as ventilation sounds or traffic noise.

4.1 Communication

The problem in schools is more complex than for example in industrial workplaces where more traditional noise reduction measures can be used. In the industrial work place the source of the noise is often a machine that can be replaced or dampened. Another traditional arrangement in industries is using ear muffs or plugs. These methods are for obvious reasons not applicable in school where the demands are high on communication and many sounds contain important information.

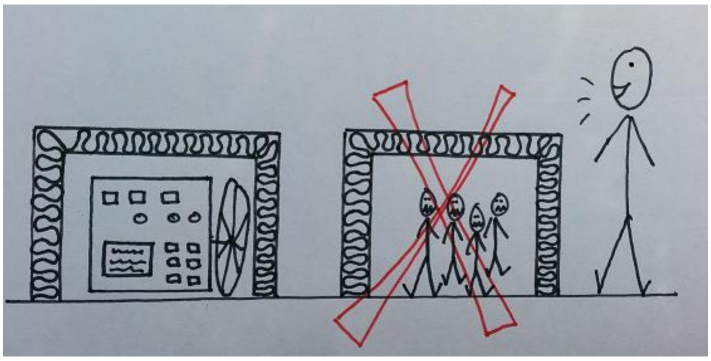


FIGURE 13. TRADITIONAL NOISE REDUCTION MEASURES CAN'T BE USED IN THE SCHOOL ENVIRONMENT.

The sounds children make cannot always be called noise because it contains a lot of important information (Sjödin, 2012). Communication amongst each other is a necessity for children's development and an important part of pedagogic processes. Every person in a school or preschool causes noise or sound. When children play they are exposed to direct sound (sound that has not reflected from any surface) amongst each other, and with large groups the sounds add up and causes a loud environment. Therefore it is not certain that all noise induced environmental problems can be solved with constructional measures such as acoustical ceilings and walls or with a well thought-out design and interior. To really lower the levels, an awareness of the issue of noise and good organization is important and has shown good results. Nevertheless, it is important to give the best conditions from the start by having premises that are well adapted to the intended activity.

4.2 Background noise

Background noise in schools comes from the additional sounds from several sources such as installations, roads and students. All these sounds combined creates a background noise that can be annoying and tiring, and need to be diminished in order to be able to converse with each other (Lewin et al, 2011). A lot of the work being done today to reduce the noise in Swedish schools is a result of restrictions from Socialstyrelsen and Arbetsmiljöverket. These restrictions are focused on the low frequency noises such as ventilation noise, but today this is not the greatest problem. The greatest source of noise in preschools and the junior levels in school are the children's voices when they play and interact and it has been shown that irrelevant speech puts a larger cognitive load on the workers than other types of noise. It is important to also lower the low frequency noise such as from ventilation and roads to obtain a calm and stress-free environment but it might not be the number one issue in the environments where the younger children are because of the high noises the children themselves make. The sound from the children have high SPL's and are at a quite high frequency level (Sjödin, 2012). These sounds are, if they don't contain any information to the receiver, perceived as more annoying than the same sound pressure would at a lower frequency (Nilsson et al, 2008).

Children that are hearing impaired or children who do not speak Swedish as their first language are in general more sensitive to background noise than other children (Persson Waye el al, 2011). With high background noise in the classroom speech ineligibility is lowered and this leads to poorer language learning. Looking at this particular problem it can be said that the issue of a good acoustic environment is a question of equality (Sjödin, 2012). It is very important for children with these particular conditions to get the chance to develop their language.

4.5 Loud noises

Outdoors very few sounds are perceived as annoying. One outdoor sound that is connected with danger and discomfort is thunder, which is a loud sound. The human being reacts in the same way indoors and have similar reactions to loud sounds here as well. Therefore they should be avoided as much as possible (Lewin et al, 2011). The measured values for teachers are often over 85 dBA, which is the limit where there are a severe risk for hearing loss and/or tinnitus according to Arbetsmiljöverket. The children (who are the source of the noise) are closer to each other and are probably exposed to even higher SPL's. It is important to remember that children have more sensitive ears than adults.

4.6 High noise levels and stress

The most stressful and noisy situation in preschool is during playtime inside (Sjödin, 2012). The noise sources that are ranked as the most disturbing are the children's voices, followed by noise from the children's activities. The time periods that corresponds to the children eating as well as their inside activities during the afternoon, are highly reflected in the number of events above 85 dBA per hour. This correlates with the teacher's experience that indoor playtime is the most stressful part of the day. Teachers who reported that they work under high stress had higher number of exposures to sounds over 85 dBA, compared to the teachers who experienced low stress. The sound levels are well correlated with the number of children present. An increase in the number of children resulted in an increased sound level, as well as an increase in the mean number of sound events over 85 dBA. When one child speaks in a loud voice it is natural that another child answers in a similar manner, which results in an increased total sound level. Under normal circumstances, when the amount of sound sources are doubled it results in a twofold increase in sound pressure (3 dB). However, when the amount of conversing people is doubled the sound level can increase up to 6 dB (Lewin et al, 2011). The children become louder when participating in a larger group due to the Lombard effect, but the level of noise generated by each child can also be affected by social interactions and individual behavioral aspects (Sjödin, 2012). This means that the size of the class is very important when it comes to noise reduction and a sure way to lower the noise levels in a class is to have a smaller group of children (Lewin et al, 2011).

The situation rated as least stressful amongst preschool teachers is when children are engaging in outdoor activities (Sjödin, 2012). This agrees with the assumption that close and immediate contact with a number of children's voices is a high stressor for the teachers. Outdoors the sound does not have the same ability to reflect like indoors, where there are hard and smooth surfaces throughout the rooms for the sound to reflect upon (Ecophon, 2011). In the outdoor environment the sound subsides with increased distance and does not echo.

When teachers rated stressors in the workplace, noise was rated highest together with conflicts among the personnel, and having children with special needs (Sjödin, 2012). The difference between the stressors is that the noise is constant and ongoing. Noise exposure in a preschool, whether it is isolated or in combination with another stressor, plays a fundamental role in the accumulation of acute as well as long-term stress. The teachers reported that their stress increased during the day, with the highest stress levels around mid-day. No one reported low energy (a symptom of being worn-out), which indicates that despite stressing factors, working with children is highly rewarding. At night, about 12 percent reported ongoing high stress levels despite being home from work. Stress and a high workload is not always a bad thing for the employees, given that they are allowed the possibility to recover. An important factor for recovery is good quality of sleep. Long time stress and sleep disturbances can lead to a burnout and a long-term absence from work.

FIGURE 14. THE LEAST STRESSFUL SITUATION FOR TEACHERS IS WHEN CHILDREN PLAY OUTSIDE. OUTDOORS THE SOUND DOES NOT HAVE THE SAME ABILITY TO REFLECT LIKE INDOORS. PICTURE TO THE RIGHT BORROWED FROM TEMPORENT (2014) AND TO THE LEFT FROM EHDIN ANANDALA (2014).

4.7 Influence on the acoustical environment from interior design

Children's behavior is an important factor in how the acoustic environment appears (Lewin et al, 2011). The environment gives a sense of how important the community thinks that school is, and this reflects on the teachers and students attitudes. There are several ways to influence people's behavior just by changing the surrounding environment such as using different colors, light settings, and screens. When it comes to light settings in schools there are standards that can be followed, but it can also be a good idea to have complementary light settings, such as a dimmer switch. This type of switch allows for the light to be dimmed during the day, for example during storytelling or lunch. We tend to slow down and be quieter in a darker environment because it indicates rest. However, it is important to take into consideration that people with hearing impairment have a need to see who's talking to be able to read their lips. Colors can change the experience of a room. If a balance between warm and cold colors is achieved, feelings of nervousness, tenseness, and anxiety can be decreased. Colors can also be used as a way to delimit the room in a natural way. This is often used in school dining rooms, where talking between the tables contributes to a loud environment. Different colored tables strengthen the sense of belonging to the group around the table and lead to less cross talk between different tables. Another important factor is the need for transition areas between different types of activities. When moving from an area where there has been a lot of activity to a calm place it takes a certain amount of time to change the mood. In school these transitions takes place in the corridors where the students for example go from class to lunch. If the corridors are designed to be relaxing and calming there is a greater chance for the students to be calm also in the dining. Background music can have a positive effect on the sound level in places like a school lunch room (Olson el al, 1998). It has been shown that when playing music in a school lunch room the sound level dropped 6-10 dB. It was also shown that music had a significant positive effect on the students' behavior when in the lunchroom. It did not matter what kind of music was played, both popular music and classical music had the same positive effect.

4.8 A study in the community of Mölndal

In a study called "God ljudmiljö i förskola" (Persson Waye et al, 2011) the acoustical environment was evaluated in preschools in the community of Mölndal, Sweden. Teachers, children, and parents answered questionnaires and participated in interviews about how they experienced the environment and how it affected their well-being. Measurements were also accomplished to see if there were any relation between the perceived SPL's and the real ones. Before the changes most preschools had plastic- or linoleum carpets for a floor and no acoustical tiles in the ceiling. The walls consisted of wooden panels about one meter from the floor and then gypsum board (both hard surfaces). Table- and chair legs had no furniture pads, which resulted in chairs scraping against the floor and emitting a loud and unpleasant sound. When taking inventory of the furniture, fabrics, and toys in the preschools it was discovered that the audio performance were often inadequately reported, and that it was hard to compare different products. This makes it hard for buyers, administrators, and users to choose interiors with the right acoustical qualities for the purpose. The technical measures taken in the study had the aim to lower reverberation time and SPL's, mostly by changes in surfaces and interior. Primarily acoustical tile ceiling was put in in all the rooms and the floors where replaced with a carpet with a silencing foam backside. From the floor and one meter up, the walls where covered with a plastic carpet with a silencing foam backside, and in the playrooms acoustical panels where placed not only in the ceilings (as in the rest of the premises) but also on the walls. Chairs and tables where all equipped with furniture pads. Tabletops in the lunch rooms had already gotten new acoustical soft surfaces before the study. These surfaces minimize the slammer and scraping sounds from tableware, glasses, and plates, which can cause annoyance. The results from the study showed that initially the teachers were very disturbed by noise but after the adaptive measures the annoyance was indeed lower. The lowering in annoyance remained when asked again nine months later, which indicates that the lowering in annoyance was not due to the expectations but were in fact real. The actual reduction in sound level was 1-3 dB which is not much considering that 1-2 dB is the limit of what can be perceived. But 3 dB corresponds to a halving of the sound pressure and this is important from an ear injury perspective. By lowering the SPL this much a person can be exposed twice as long without risking hearing loss. In the study more than half of the children reported strong, high pitched sounds "often or really often" and even more heard angry or yelling noises. Unfortunately, these noises were the same before and after the measures were made. This is probably because the noises from screaming and yelling amongst the children are direct sounds and do not reflect from any absorbent surfaces before reaching the receivers (the other children). However, the sounds that were described as "piercing" or "tearing" decreased significantly after measures. These noises probably came from the chairs scraping against the floor and the new floor materials and furniture pads in combination with the absorbents diminished these sounds. In the study there were also a significant decrease in people reporting sound fatigue, being tense and having headaches after the measures. This shows a connection between the new environment and an improved health.

4.9 Aircraft and road noise

Aircraft and road noise have been shown to have an adverse effect on both health and cognition (Stansfeld et al, 2005). Environmental stressors can have a great effect on the degree to which information is being processed. Children can be particularly sensitive to the effects of noise because of its interference with learning and critical developmental stages. Children also have less capacity than adults to anticipate, understand, and cope with stressors. Chronic aircraft noise is associated with a significant impairment in reading comprehension. A 5 dB difference in aircraft noise corresponds to a 1-2 month delay in reading development. Aircraft and road noise has also shown to have an impact on long-term memory. The size of the effects does not differ by socioeconomic status.

4.10 Using the budget properly

Often only limited budgets exist for improving the environment in preschools and schools, which makes it particularly important to use the money in a smart way to achieve the best results (Lewin et al, 2011). As a result of the restrictions, a lot of the money is used to install new, quiet ventilation systems when the money, in some cases, would be better spent on the interior that absorbs frequencies around children's speaking level. In the long term there is an economical advantage to designing schools in a way that prevents high noise levels already in the planning process, because changes that are made later on generally turn out to be more expensive.

5. Office

5.1 History

Today's office types are a product of what has been evolving during the last century. In the beginning of the 20th century, office spaces where designed to follow the way the paperwork would go (Ivarson et al, 2009). This resulted in large open-plan offices where the employees sat side by side, with the intention of making work more efficient (figure 15).

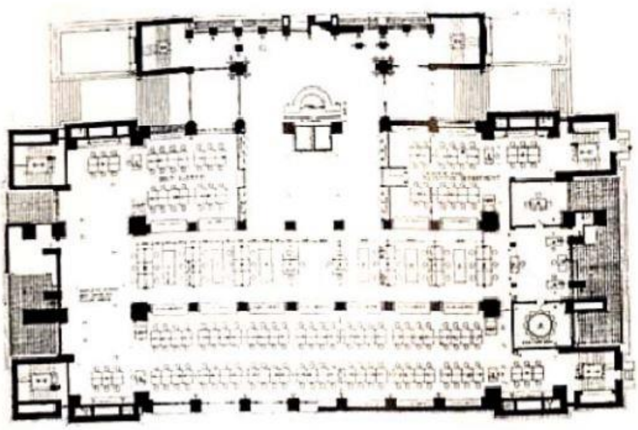


FIGURE 15. OFFICE LANDSCAPE FROM THE EARLY 20TH CENTURY (IVARSON ET AL., 2009).

After World War I there was an increased interest in people's health and wellbeing. The result was the cellular office (figure 16), where one or two people sat together in a room with the possibility of closing a door for privacy. As the offices were located in a row along a corridor, this resulted in very long buildings.

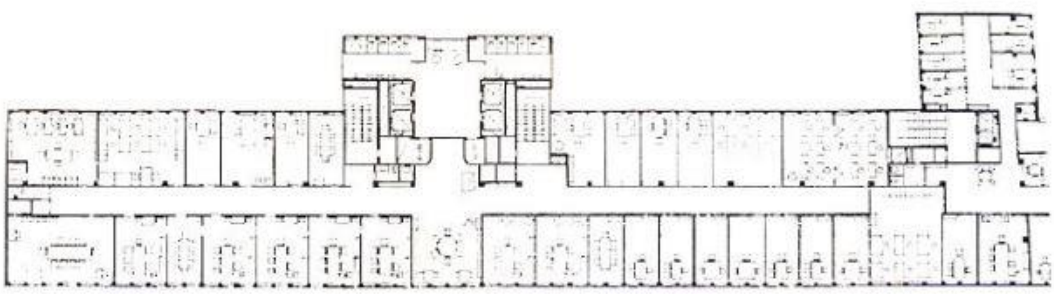


FIGURE 16. CELLULAR OFFICE (IVARSON ET AL., 2009).

In Germany the interest of a more efficient office, with a higher worker density, grew in the 50's. It was believed that the cellular office had complicated the communication- and information-flow. The open-plan office was again reintroduced but this time screens where installed to separate workstations (figure 17). At this time Sweden had regulations on light-, noise-, and air-quality that could not be fulfilled in the open-plan office. This resulted in Swedish companies keeping the cellular office solution.

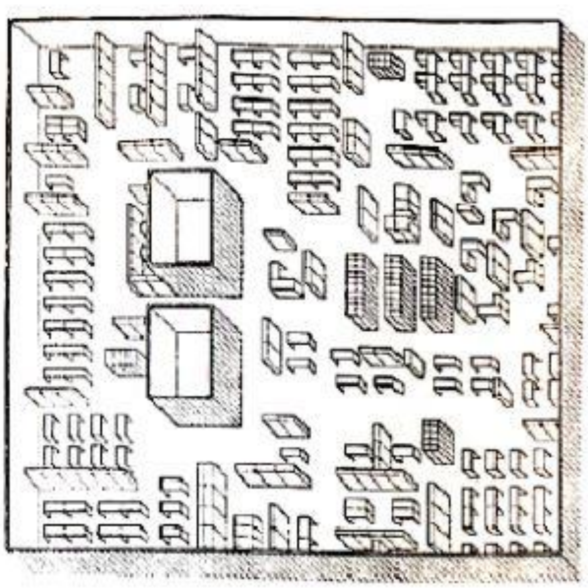


FIGURE 17. OPEN PLAN OFFICE FROM THE 50'S (IVARSON ET AL., 2009).

In Germany the offices continued to develop. In the 80's a combination between the cellular office and the open-plan office began to take form, a so called "combination office". The expectation was to counter the disadvantages with both types of offices. It resulted in a cellular office but with glass walls out towards a common space that could be used for group activities, discussions, breaks etc. In the 90's when the number of IT-companies increased the request for office space grew and the square-meter-price went up. The companies wanted to lower the costs for office space by using less space for their employees. As the computer became the main working tool the need for a private office space was no longer as important. Every employee received a portable drawer where they could keep personal belongings and simply choose an unoccupied space to work in for the day. This type of office space is called a "flex space" and can be suitable if employees do not work in the office every day, but are out with costumers or work from home some of the time. Figure 18 shows both the combination office and the flex office.

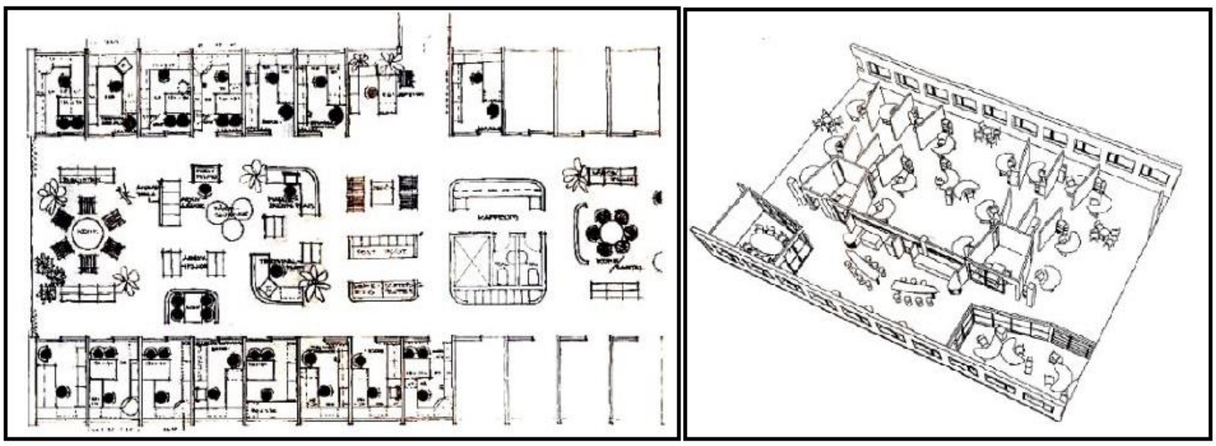


FIGURE 18. COMBINATION OFFICE TO THE LEFT AND FLEX OFFICE TO THE RIGHT (IVARSON ET AL., 2009).

5.2 Open-plan office and cellular office

The open-plan office and the cellular office have the greatest acoustical differences and will be investigated closer in the remaining chapter.

Today there is an increasing trend worldwide to build open-plan offices when building new office spaces or when renovating current spaces (Kaarlela-Tuomaala et al, 2009). The reason why the open-plan office has become popular is lower building expenses due to the smaller amount of partition walls, lower rent costs since a higher worker density is possible, better adjustability, and better access to daylight. This gives an economical advantage for the property owner and the company renting the office space. Architects usually prefer the open-plan solution because it is less enclosed.

According to Christina Bodin Danielsson et al. (2008) the far most wanted office type amongst employees is the cellular office. The only disadvantage for this type of office space, in comparison with other types of offices, is the lack of perceived sense of fellowship. Advocates of open-plan offices believe that they promote cooperation and social relations but there is no scientific evidence to actually support these beliefs (Kaarlela-Tuomaala et al, 2009). Lack of privacy (both visual and acoustical), increased distraction from noise, reduced workstation size, and uncontrollable social contacts/interruptions are the most feared features of the open-plan office space.

5.2.1 Cubicles or bullpens

The lack of privacy and the human-borne noise (people talking in the phone, discussing with colleagues etc.) are the environmental factors that cause the most dissatisfaction for employees after relocating from private offices to open-plan offices (Kaarlela-Tuomaala et al, 2009). Privacy in open-plan offices with very low screens (bullpens) are significantly lower than in the ones where workstations are enclosed by high screens (cubicles).The difference between bullpens and cubicles are shown in figure 19. There are two types of cubicles: high-paneled and low-paneled. The employees cannot see each other when seated in the high-paneled cubicle. Higher screens allow better sound absorbance and more visual privacy than the lower ones. The geometry and the size of the room also have a significant importance on the acoustical environment. A long, narrow room generates a lot of reflections that can have an impact on both the noise level and speech intelligibility (figure 20). Also, good speech privacy is easier to achieve in large open-plan offices than in small or medium ones, because of lower intensity of room reflections.

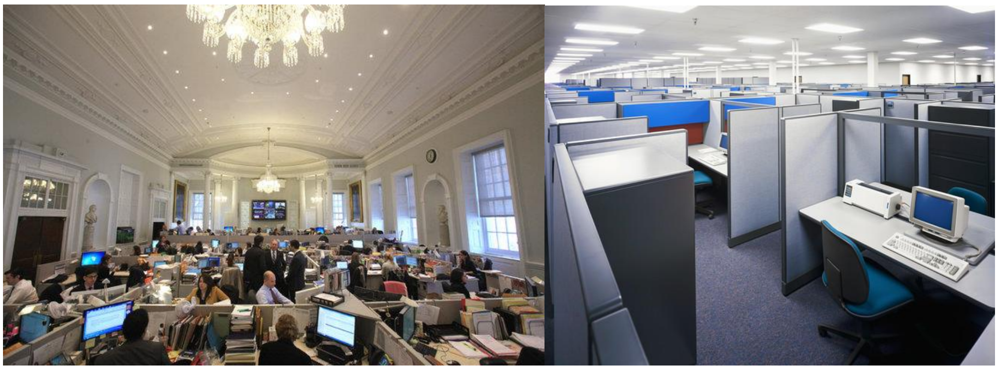


FIGURE 19. CUBICAL TO THE RIGHT (THE CURATOR, 2014) AND BULLPEN TO THE LEFT (NEW YORK TIMES, 2014). MORE VISUAL AND ACOUSTICAL PRIVACY CAN BE ACHIEVED WITH THE CUBICAL.

5.2.2 Speech intelligibility and its impact on task performance

The speech transmission index (STI) is a good measure to find out how disturbing background noise is and directly expresses the level of subjective speech disturbance. In an office where the acoustics are well designed (with absorbents in ceilings and screens, masking sounds etc.), the speech is intelligible within about 5 meters from the speaker, compared to an office with a poor acoustic environment where speech can be intelligible up to 20 meters from the speaker. At long distances, such as 20 meters, it is almost certain that intelligible speech will be perceived as an unwanted sound, which will result in concentration problems and affect the ability to perform cognitive tasks. When speech is present in a private office it is typically useful for the worker because it signals that a colleague is visiting the room. Task performance is at its best when speech does not exist (STI = 0). Performance start to reduce when STI exceeds 0.3 and the lowest performance level is reached at an STI of 0.6. In the STI range 0.6 to 1.0 the speech intelligibility is perfect. In other words it is more difficult to perform a task when speech is present but not intelligible (Kaarlela-Tuomaala et al, 2009). It is suggested that the speech intelligibility is more important than loudness of speech. This is supported by the fact that the background noise level does not influence the performance when the A-weighted SPL is within the normal comfortable range of hearing (below 80 dB), and the spectrum of background noise is smooth and comfortable. When comparing the STI between two neighboring workstations in an open-plan office and two neighboring cellular offices, the STI values were significantly lower between the cellular offices (0.22 in cellular office with closed door and 0.76 in open-plan office). This predicts a higher disturbance from speech between two neighboring workstations in an open-plan office with low background noise level and low amount of room absorption. The SPL's from speech were lower in the cellular office than in the open-plan office (41 dBA and 52 dBA respectively). The higher SPL's in the open-plan office might not be distracting, but it is more difficult to converse without raising your voice. This can, in turn, lead to a negative spiral effect where the sound levels are increasing.

The simultaneous use of absorption materials, sound absorbing screens, and speech masking systems produces the lowest STI, which results in the best speech privacy in open-plan offices. The recommended background noise level from masking sounds is 42 dBA and in a study presented on a Euronoise conference (2012) this sound level was found to be non-disturbing for most people (4 out of 5), when using a masking system playing a pink noise.

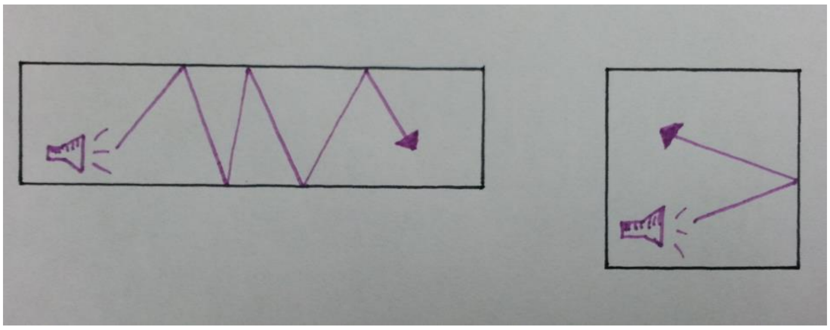


FIGURE 20. THE SAME SOUND CAN CAUSE MORE ROOM REFLECTIONS IN A NARROW ROOM THAN IN A WIDER ROOM.

5.2.3 Annoyance by noise

The amount of annoying noise is directly connected to the amount of telephone work, conversations, and laughter in the open-plan office. To compensate for the environmental changes that decreases employee's ability to work, they may change their strategy for doing a task (Kaarlela-Tuomaala et al, 2009). For example, some people choose to take work home instead of sitting in the office. The same study also says that the satisfaction with the work environment as a whole decreases after relocation to open-plan offices. Workers are more satisfied with the acoustical environment in the cellular office rooms, but other factors, like too high/low temperature or bad air quality, can be improved in an open-plan solution. However, despite some improvements the disturbance by all the indoor factors summed up is greater in the open-plan office. The self-estimated waste of working time doubled after a relocation from cellular offices to an open-plan office. After relocation the employees experienced significantly less privacy and peace for working. Also cooperation became significantly less pleasant.

5.2.4 Well-being and health

As mentioned before, the self-rated comfort and well-being is highest in cellular offices (Bodin et al, 2008). This is also the type of office that people to the greatest extent wished that they had. When looking from a health perspective the flex-office is the best and it is also quite popular amongst employees. This is a contradiction as the flex-office appears to be the exact opposite from the cellular office but this has an explanation. It is well known that people's health and perceived well-being is directly connected to the amount of self-assigned time. In the cellular office people are trusted to sit by themselves and work. The same concept applies for the flex-office where people can choose to come and go, work from home, or from the office. The free choice results in people being more comfortable at work. Both of these office types also gives the option to sit in peace and quiet if needed. This makes it easier to perform high-pressure cognitive tasks like reading, processing of text, or solving mathematical problems. The lowest rated satisfaction with the work place is found amongst employees in medium sized open-plan offices.

6. Summary of important parameters

Below, a summary has been compiled of important parameters to consider when designing a hospital, school, or office building. It includes both parameters that are directly connected to building acoustics as well as other parameters, which are not directly related but still have an important impact on the acoustical environment as a whole.

6.1 Hospital

6.1.1 Parameters connected to building acoustics

- Choose the site location and take into account existing and future airports and highways.
- Keep noise in outdoor patient areas under 50 dBA. Noise barriers can be used.
- Use sound insulating windows and make sure they are airtight.
- Establish the usage of the room before deciding what acoustical measurements could be suitable.
- If possible: have single patient rooms for all patients. If this is not possible: strive to let the most ill patients get privacy. Also consider meeting rooms where patients, relatives, and health care employees can have private conversations without disturbing, or being disturbed by others.
- Keep the noise in corridors down by minimizing the use of thresholds.
- Decentralize the nurse's stations to further keep noise from corridors to a minimum level.
- Build all walls from floor to the underside of the next floors structural deck.
- Consider sound proofed windows and doors. Look out for air gaps.
- Rubber floors are better than vinyl composition tiles.
- Use acoustical ceiling tiles.

6.1.2 Other important parameters

- Keep the noise in corridors down by minimizing the use of portable carts.
- Install sound masking systems.

6.2 School

6.2.1 Parameters connected to building acoustics

- Reduce background noise from students by using absorbing materials (like acoustical tiles) in ceilings and on walls. Also use an interior that absorbs sound well such as curtains, carpets, and other textile objects. In preschool, and the lower grades in school, it is more important to dampen noise from students than to diminish low frequency noise.
- To achieve an over-all stress free environment, reduce low frequency noise by installing ventilation systems that reach BBR's standards for SPL's. Façade insulation as well as sound proofed doors and windows are important to keep out unwanted noise from roads.
- Create transition areas that give people a chance to change their mood between activities. Design relaxing and calming corridors in schools.

6.2.2 Other important parameters

- Smaller groups is the absolute key to lower the SPL's in class rooms. Less students result in lower SPL's.
- Install complementary light settings (dimmer switch) to use during, for example, storytelling or similar activities.
- Increase the ability to have more time outdoors, maybe by having larger schoolyards. Fences should be installed when the school is located near roads with traffic.
- Use colors to create an environment that is less stressful. Colors can also be used to delimit the room.
- Use background music in lunch room or class rooms. Use a variety of music categories.
- Use furniture pads on table- and chair legs to limit the scraping noises.

6.3 Office

6.3.1 Parameters connected to building acoustics

- Consider the geometry and size of the room. A small or medium sized open-plan office can give a lot of room reflections. A large open-plan office is better than a medium or small one.
- Use ceiling absorbents.
- Do not allow an STI between 0.3 and 0.6. An STI at 0.6 is the worst case scenario. A low STI is more important for the ability to perform cognitive tasks than a low SPL.

6.3.2 Other important parameters

- Employee's health and perceived well-being is directly connected to the amount of self-assigned time.
- The lowest rated satisfaction with the work place is found amongst employees in medium sized open-plan offices.
- The highest rated satisfaction with the work place is found amongst employees in cellular offices and flexi-offices.
- The recommended level from sound masking systems in open-plan offices is 42 dBA.
- Simultaneous use of high sound absorbing screens (high-paneled cubicles), speech masking sound, and absorption materials such as for example curtains produces the lowest STI.

7. The sound environment at home

Not much research has been done on the home environment and what acoustical challenges can be found in these types of buildings. By using the data from research that exists in hospitals, schools, and offices a method for evaluating the sound environment at home is presented below.

A residence can be divided in following room types:

- Bedroom
- Kitchen
- Living room/TV-room/dining room
- Hallway
- Bathroom

Each room type has the need of different acoustical approaches to function for its sole purpose. There should be both spaces that encourage social relations as well as privacy. A summary is shown in the mind map on following side.

7.1 Bedroom

As mentioned earlier in this thesis, good quality of sleep is a biological necessity and very important for basic human functions. To minimize unnecessary changes in sleep structure, a low SPL (around 30 dBA) is desirable. Considering that the bedroom is the most important room to have low background noise levels in, it should if possible be facing away from busy streets. Today, the open-plan solution is popular not only in office buildings and hospitals but also in homes. However, it is beneficiary to separate at least one room from the rest of the dwelling, to have the possibility for both acoustical and visual privacy. This type of room is also suitable for tasks that require concentration, for example solving cognitive tasks.

7.2 Living areas

The living areas (living room, TV-room, dining room etc.) purpose is social interactions. There is no particular disadvantage for these areas to be open-plan. An open-plan solution gives better access to daylight and feels less enclosed. The geometry of this room can have an impact on the acoustical environment. A long, narrow room generates more room reflections that can have an impact on both the noise level and speech intelligibility if many people are conversing.

7.3 Kitchen

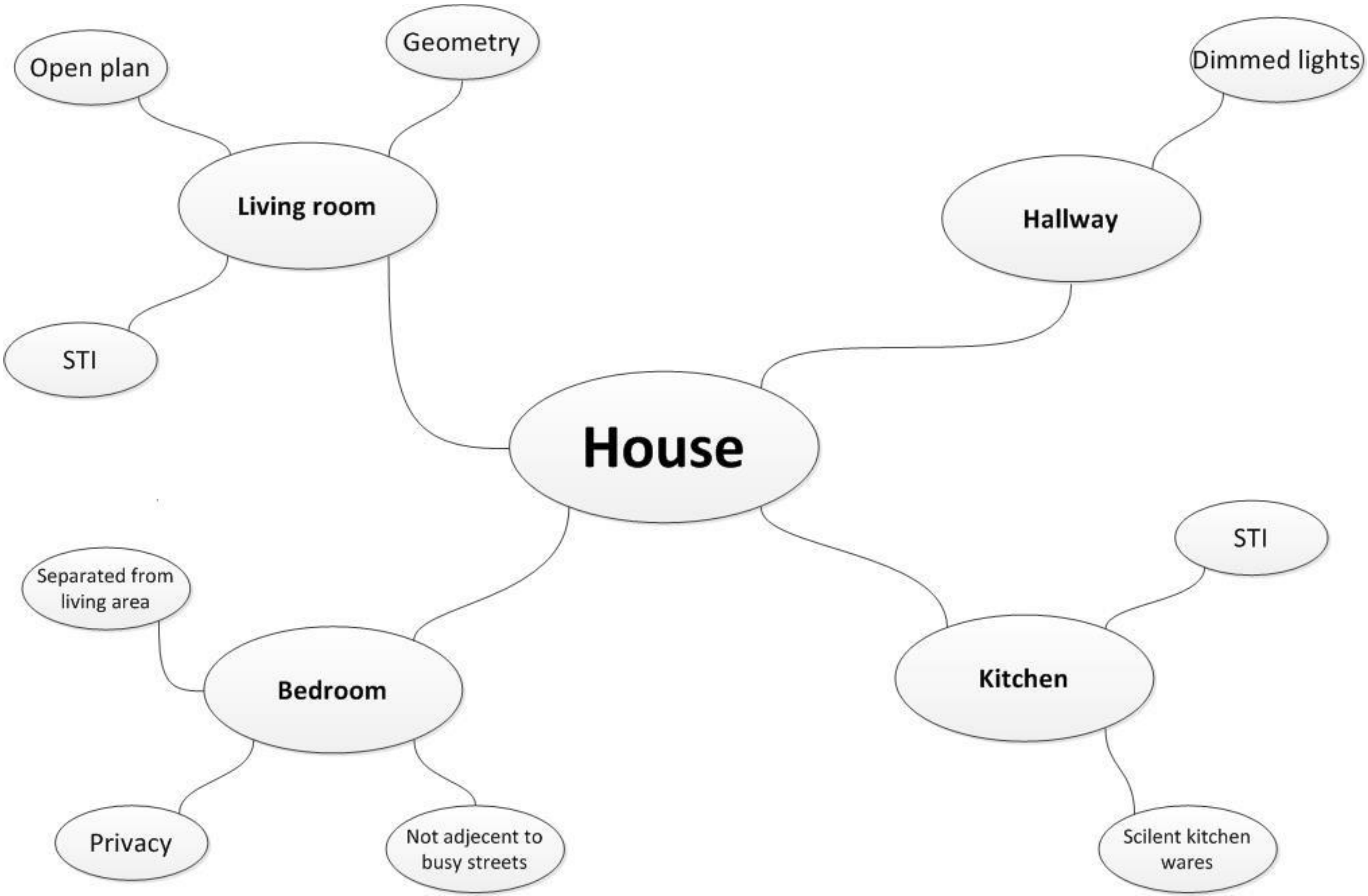
The kitchen can be a separate room or connected with the living areas. All kitchenware, including ventilation, should be as silent as possible. The sounds they generate contain very little valuable information and will therefore with certainty be perceived as noise. If the kitchen is connected to the living areas in an open-plan solution it is of even greater importance that the kitchenware indeed is silent. Most new kitchenware has a quite low sound level. If possible, best acoustical comfort will be obtained if all kitchenware has SPL's under 50 dB, or as silent as possible. The limit of 50 dB is a reasonable limit considering today's available product range.

7.4 Hallway

The bedroom is supposed to be a room of relaxation while the living area invites to social interaction. A transition area between these two types of living spaces can be a good idea because we need a little time to change mood before entering the next room. This can be accomplished with hallways with dimmed lights installed, as we tend to move slower in a darker environment.

7.5 Bathroom

The bathroom is an acoustical challenge due to the many hard surfaces, but as we spend very little of our time in this area, it is not considered an issue with poor acoustics here.


Open plan
Geometry
Living room
STI
Dimmed lights
Hallway
House
Separated from living area
Bedroom
Privacy
Not adjecent to busy streets
STI
Kitchen
Scilent kitchen wares

8. Discussion

All the studies that have been the base for this thesis have used measurements of SPL's, STI etc. but have also contained interviews. Using interview with the people living/working/staying in the premises on a daily basis can give information about how different acoustical phenomenons are related to our well-being and health. All studies point in the same direction: a poor sound environment decreases both the actual and the self-rated well-being.

Stress is a central part of today's society and to be able to cope with it we need the places where we spend major parts of our day to be tolerable. When exposed to noise during a long time, levels of stress hormones are constantly high, which is not good for our health. The strain on the body causes both physiological and psychological problems such as cardiovascular diseases, sleep disturbances, depressions, and burn outs. All these are common conditions that cost the society a lot of money in medical bills every year. To lower these types of diseases it is very important for each individual, simply to be able to live a full life. Seeing to economics, one can argue that it also has great importance for the society as a whole.

An important knowledge to take from this thesis is that noise leads to changes in sleep structure. This is not necessarily obvious to the person being exposed to loud nighttime noises, but can affect the individual subconsciously. However, disruptions during sleep will impair sleep quality, which in turn can lead to health problems, mostly connected to the increased level of stress hormones.

The different types of environment that have been studied all have obvious connections with the home environment despite the fact that hospitals, schools, and offices are workplaces. To be able to both rest and take care of social relations are reasonable demands to put on a dwelling.

Different types of sound environments need to be evaluated and treated in different ways. To evaluate what noises are problematic in each situation is crucial for how good of an acoustical environment that can be created. In most cases it is more difficult and more expensive to fix a poor sound environment in retrospect, which makes it a smarter move to consider these parameters immediately in the planning process.

Building acoustics build the foundation on which to create a good sound environment. It is obvious that acoustics needs to be considered throughout the whole construction process since sound can travel in many ways that are not always obvious. However there must be a consistent consideration of the acoustics, from planning and building to interior design. Just applying acoustics strictly to the construction stage is often not enough to create a good sound environment.

9. Conclusions

When comparing sound environments it is most common to search for differences. However, this thesis shows that there are also a lot of similarities. The main goal is always the same: create a stress-free environment that benefits people's health and well- being. Building acoustics can help create good sound environments but it is also important to see that there are other important parameters that also play a major roll. It is not only the people that are involved in the construction phase that need to be aware of the impact that noise can have on health and well-being. With an all-round awareness of what impact noise has on everyday life, people can actively work to influence the sound environment in their surroundings. Finally, the home environment has many similarities with other common sound environments. Seeing that the home environment is still not the focus of any major research, it is reasonable to apply some of the parameters that have been found to be important in other sound environments, also on the home environment. With the increasing level of stress in today's society, a home with the possibility for recovery seems more important than ever.

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