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# An Architectural Design Guideline for Pain Hyperacusis Patients: Silent House Typology

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**Abstract** Pain hyperacusis is a serious hypersensitivity condition, where patients feel pain because of everyday sounds. As there is no common medical treatment method for this condition for the time being, patients need to protect themselves against noises, which actually would be defined as daily standard sounds by people with normal hearing. This protection has to be mostly spatial due to the very nature of the sound. Users' needs define the architecture and the spaces created. In this paper, a new "silent house" typology is proposed as a functional group of buildings, with an architectural acoustics design guideline. Recommendations for upper-scale decisions, plans, sections, layers, materials and mechanical installations are given as design strategies. The importance of using heavy and layered walls, floating floors, suspended ceilings and flexible connections is stated. Also, a case study of Barbaros House is presented as a silent house example designed for a pain hyperacusis patient, with the conducted acoustic measurements. Reverberation times, background noise levels, outdoor sound pressure levels $L_{1,2m}$ at a distance of 2 m in front of the facade, sound pressure levels $L_2$ in the receiver room, and $D_{ls,2m,nT}$ sound insulation values for 1/3 octave band frequencies are given in the results part. The single-number quantity $D_{ls,2m,nT,w}$ ($C$; $C_{tr}$) of this house was measured as 54 (-1; -3) dB. Aural diversity and the need for awareness about this topic are mentioned.

**Keywords** Noise Control, Architectural Typology, Silent House, Pain Hyperacusis, Noxacusis, Quiet Areas, Aural Diversity

## 1. Introduction

Noise is defined as unwanted sound [1]. It depends on the context and the person themselves, whether a sound is wanted or unwanted. Individuals can have different preferences about what they like to hear. The sound doesn't have to be loud to be defined as noise. A person with normal hearing can dislike a certain type of music, and that music can be defined as noise for that person. Also, after a busy day, people may not want to listen to a song that they would normally enjoy. In this context, people with decreased sound tolerance can call some sounds noise, which can be defined as everyday sounds by people with normal hearing.

Unlike other sound sensitivity disorders like loudness hyperacusis, annoyance hyperacusis and fear hyperacusis, decreased sound tolerance can also include physical pain in pain hyperacusis cases. Since there is currently no cure for this condition, pain hyperacusis patients need to control the sound environment, especially in their homes where they spend their time resting and sleeping. Thus, the acoustic design decisions in these special houses need to be carefully taken. There is no common system or typology for these patients, although basic principles of acoustic precautions are set. In this research, the methodology of the study is explained, a detailed literature review about sound sensitivity disorders and pain hyperacusis is given, auditory and spatial needs of pain hyperacusis patients are stated, current typologies and architectural typology proposals for individuals with different needs are mentioned, a silent house typology is proposed, and a design guideline for this typology is given, including upper-scale decisions, plan and section scheme recommendations, materials, layers and mechanical installations. Also, a case study of Barbaros House is analyzed in terms of acoustic design decisions, and relevant objective site measurement results are stated with the necessary measurement equipment information.

# 2. Methodology

In this study, qualitative and quantitative research methods were used to develop a housing typology for the spatial and auditory needs of pain hyperacusis patients. A literature review was conducted, the types of sound sensitivity disorders were revealed, and a house design guideline specific to pain hyperacusis patients was proposed. Medical literature on hyperacusis was reviewed and sources addressing sound-related design approaches at the residential scale were investigated. Qualitative data from literature were evaluated to understand the spatial problems patients face in their daily lives and their expectations for solutions. Urban and architectural initiatives focused on silence were also considered as guiding examples. In the final phase, based on the findings, a design guideline for a "silent house" typology for hyperacusis patients was developed. This proposal includes upper-scale layout decisions, plan and section recommendations, and architectural solutions for building materials and layers. Design parameters were developed considering both user needs and scientific data on room acoustics and noise control. Acoustic measurements were conducted as a case study on a residential building designed and constructed in accordance with these criteria and the results were presented as quantitative data.

# 3. Literature Review

### 3.1. Sound Sensitivity Disorders and Decreased Sound Tolerance

Perceiving sounds can be different among people. Aural diversity describes the plurality of hearing senses [2]. Normal hearing is defined as hearing of otologically normal persons who are in a normal state of health and who are free from all signs or symptoms of ear disease between the ages of 18 and 25 [3]. For most individuals, the period of experiencing 'normal' hearing is relatively short, which means that everyone perceives sound differently [2].

Exposure to everyday sounds is a significant problem for some people [4]. Sound tolerance conditions can be grouped under the titles of hyperacusis, misophonia, noise sensitivity and phonophobia [4]. Hyperacusis, phonophobia and misophonia are subclasses of decreased sound tolerance [5]. As a definition, hyperacusis describes physical discomfort or pain due to a sound with a loudness level that would be tolerable for most people. Misophonia refers to intense emotional reactions to certain sounds like chewing and sniffing, where the loudness of those sounds is ineffective. Phonophobia is defined as the anticipatory fear of sound which is an emotional response such as anxiety [4].

In another research, different name suggestions for the types of hyperacusis were introduced as loudness hyperacusis, annoyance hyperacusis, fear hyperacusis and pain hyperacusis [6]. According to these definitions, loudness hyperacusis is the case where moderately intense sounds are judged to be very loud. A negative emotional reaction to sounds is called annoyance hyperacusis. Fear hyperacusis is defined as an aversive response to sounds which leads to anticipation and avoidance. Pain hyperacusis is the type of hyperacusis where the patients experience pain at much lower sound levels than listeners with normal hearing [6].

### 3.2. Pain Hyperacusis (Noxacusis)

Among the sound sensitivity disorders mentioned above, pain hyperacusis is the main focus of this research, as patients require special living conditions, where everyday sounds need to be controlled. Pain hyperacusis is a new term for the diagnosis in the field and has been recognized only in the last ten years, as seen in Table 1. Pain hyperacusis is referred to as noxacusis in some research articles. Web of Science Core Collection, Scopus and PubMed databases were searched for "pain hyperacusis" and "noxacusis" in titles, abstracts and keywords (title-abs-key), without any limitation in publication year, and results were given in Table 1. It can be mentioned that limited research has been conducted regarding this topic.

Pain hyperacusis patients experience noise-induced pain [19]. This severe pain is reported as a stabbing pain in the ear or the head [6]. Besides pain, comorbid otologic symptoms like aural fullness, a feeling of pressure within the ear, tinnitus and fluttering of the eardrum are often reported [7].

A recent study where clinical phenotype and management of sound-induced pain is introduced through insights from adults with pain hyperacusis [7] shows that patients reported sound-induced burning, stabbing, throbbing, and pinching sensations that occur either in the ear or elsewhere in the body. It is also stated that 100% of the questionnaire participants changed their lifestyles due to pain hyperacusis. When a comparison of loudness and pain hyperacusis is made, individuals with pain hyperacusis present a more severe clinical phenotype. They reported a higher frequency of setbacks (temporary symptom exacerbations) and less perceived symptom improvement over time [8]. It is stated in many reports and articles that pain hyperacusis patients have reduced benefits or no benefits at all from sound therapy [8], while in some cases sound therapy even worsens the condition [7]. There is no literature that evaluates the efficacy of sound therapy and cognitive behavioral therapy for pain hyperacusis patients [7].

**Table 1.** The use of pain hyperacusis and noxacusis terms in literature

| Article name | Author(s) | Year | Journal | Database | Title-Abs-Key |
|---|---|---|---|---|---|
| Clinical phenotype and management of sound-induced pain: Insights from adults with pain hyperacusis [7] | Jahn, KN; Kashiwagura, ST and Yousuf, MS | 2025 | The Journal of Pain | WOS Core Collection, Scopus, PubMed | "pain hyperacusis" "noxacusis" |
| A Phenotypic Comparison of Loudness and Pain Hyperacusis: Symptoms, Comorbidity, and Associated Features in a Multinational Patient Registry [8] | Williams, ZJ; Suzman, E and Woynaroski, TG | 2021 | American Journal of Audiology | WOS Core Collection, Scopus, PubMed | "pain hyperacusis" |
| Hyperacusis in chronic pain: neural interactions between the auditory and nociceptive systems [9] | Suhnan, AP; Finch, PM and Drummond, PD | 2017 | International Journal of Audiology | WOS Core Collection, Scopus, PubMed | "pain hyperacusis" |
| Hyperacusis: major research questions [10] | Baguley, DM and Hoare, DJ | 2018 | HNO | WOS Core Collection, Scopus, PubMed | "pain hyperacusis" |
| The Sound Sensitivity Symptoms Questionnaire Version 2.0 (SSSQ2) as a Screening Tool for Assessment of Hyperacusis, Misophonia and Noise Sensitivity: Factor Analysis, Validity, Reliability, and Minimum Detectable Change [11] | Aazh, H and Kula, FB | 2025 | Brain Sciences | WOS Core Collection, Scopus, PubMed | "pain hyperacusis" |
| Interaction of auditory and pain pathways: Effects of stimulus intensity, hearing loss and opioid signaling [12] | Manohar, S; Adler, HJ; Radziwon, K and Salvi, R | 2020 | Hearing Research | WOS Core Collection, Scopus, PubMed | "pain hyperacusis" |
| Commentary: Consensus definition of misophonia [13] | Aazh, H | 2023 | Frontiers in Neuroscience | Scopus | "pain hyperacusis" |
| Nociception in Pain Hyperacusis [14] | Colucci, D.A. | 2021 | Hearing Journal | Scopus | "pain hyperacusis" |
| Effective Management of Pain Hyperacusis [15] | Colucci, D. | 2017 | Hearing Journal | Scopus | "pain hyperacusis" |
| Damage-evoked signals in cochlear neurons and supporting cells [16] | Wood, MB, Nowak, N, and Fuchs, PA | 2024 | Frontiers in Neurology | WOS Core Collection, Scopus, PubMed | "noxacusis" |
| Unmyelinated type II afferent neurons report cochlear damage [17] | Liu, C, Glowatzki, E and Fuchs, PA | 2015 | Proceedings of the National Academy of Sciences of the United States of America | WOS Core Collection, Scopus, PubMed | "noxacusis" |
| The diversified form and function of cochlear afferents [18] | Fuchs, PA | 2018 | Oxford Handbook of the Auditory Brainstem | Scopus | "noxacusis" |

Noise pollution is called a modern plague [1] and it is argued that ambient noise is the new secondhand smoke [20]. It can be imagined that ambient noise to pain hyperacusis patients is what secondhand smoke is to asthma patients. In the study of Perreau et al. [21], 100% of the participating patients stated that removing themselves from noisy situations reduces their hyperacusis. Also, most patients reported that being in a quiet environment is especially helpful in reducing hyperacusis pain. The participants of the questionnaire study of Jahn et al. [7] stated that they feel they must control the environment around them to reduce hyperacusis symptoms. Patients with pain hyperacusis must protect themselves against noise. Noise worsens pain hyperacusis, whereas quiet supports healing. Earplugs and earmuffs are only effective to a certain extent. They can be ineffective at reducing especially low frequencies due to their sizes. Low frequency noise is generally found to be difficult to control [22]. Thus, protection against noise is only possible spatially, i.e. with properly designed building elements.

### 3.3. Auditory and Spatial Needs of Pain Hyperacusis Patients

#### 3.3.1. Requirements in Urban and Architectural Context

Pain hyperacusis patients need to protect themselves against noises. Especially when they are out of their houses, they need practical protection like earplugs on the streets, inside vehicles, in shopping malls, in short, everywhere where there is sound. Patients might avoid leaving the house, which may lead to social isolation [7]. In urban context, there is certainly a need for more silent open and closed public spaces without traffic and background music noise.

In terms of architectural recommendations and interventions in literature, in the study of Wiesel and Power, a questionnaire participant responds to a question about their housing preferences with the answer “A quiet environment at home, e.g. thick walls, supports my hyperacusis” [23]. In another article, Johnson [24] recommends double- or triple-glazed windows, or an additional window for hyperacusis patients as an architectural improvement, along with other suggestions about kitchenware, appliances and potential risky conditions. It is recommended to start soundproofing with rooms where the most time is spent [24]. Cohen [25] reports that architectural changes like soundproof windows help reduce the exterior noise, and replacing interior doors with solid wooden doors makes a difference in blocking noise between rooms. Also, the neighbors on the upper floor, who use plush rugs with felt padding beneath as floor covering, can contribute to noise prevention [25].

#### 3.3.2. Accessibility for Pain Hyperacusis Patients

Pain hyperacusis can be considered as a disability for patients who face obstacles in many spaces they must enter. Sound is everywhere in urban life. Sounds that do not bother people with normal hearing can cause long-lasting pain in patients with pain hyperacusis. This results in social isolation. Efforts are being made to improve the conditions for the physically disabled and visually impaired individuals in an architectural sense through laws and regulations. For individuals with hearing impairments, disability is generally addressed through hearing loss and deafness. Ambient noise is a disability rights issue for individuals with hearing loss and hyperacusis [26]. Noisy restaurants and stores deny full enjoyment and equal participation in public life to hyperacusis patients, where actually improving the conditions is easily possible by turning down the amplified sound [26] or not having the amplified sound at all. Accessibility for individuals with pain hyperacusis is only possible by reducing environmental noise. Solutions to provide quiet environments in daily life are possible through legislation and regulations in terms of business operations and spatial organizations. As a start for these implementations, it is suggested to adapt the existing standards for classroom acoustics to restaurants and stores, or to specify indoor sound levels suitable for people with auditory disorders [27]. Individuals with auditory disabilities don’t need special treatment; they need a universal design environment, free of auditory barriers, to participate fully and equally in life [26]. This can be achieved through inclusive design for all people [28]. Also, creating awareness about noise and aural diversity is one of the first important steps that can be taken in solving problems. Self-awareness and other’s awareness together can form a joint awareness which leads to better understanding and managing noise-related problems [29].

#### 3.3.3. Civil Society Organizations

There are civil society organizations (CSOs), networks, platforms and initiatives which have silent spaces and silence on their focus. A non-profit organization, Quiet Communities, promotes quiet as a valuable natural resource and works to reduce harmful noise and related pollution with the sub-programs called Quiet Coalition, Quiet Healthcare, Quiet Restaurants, Quiet Streets, Quiet Skies and Quiet Landcare. Also, Noise Abatement Society deals with noise problems as a charity. There are also organizations which promote background music-free public spaces, shops and restaurants like Pipedown and Spaces without Music [30]. As a guide for hyperacusis patients, the restaurant lists of these campaigns can be beneficial. Stille Stunde (Quiet Hour) is also a campaign, where supermarkets voluntarily agree to turn off the background music and dim the lights at least once a week for individuals with sensory sensitivities. Aural Diversity Network is another platform which seeks to address the complex picture by researching differences in hearing and listening. Furthermore, there are organizations more specific to hyperacusis and hearing disorders like Hyperacusis Central, Hyperacusis Research and Hearing Health Foundation. All these organizations help to raise awareness about noise and hyperacusis. International Noise Awareness Day, which is commemorated on the last Wednesday of April each year, has also been a global campaign since 1996. In a recent study, pain hyperacusis patients’ need for music-free spaces was stated [31], and a summary of above-mentioned organizations was given.

### 3.4. Architectural Typologies

#### 3.4.1. Current Typologies in Literature Associated with Sound

Typologies collect buildings into groups according to their functions or forms. Many typologies in architecture are closely related to acoustics due to their functions. Especially spaces like concert halls and recording studios, which are directly related to a listening function, require soundproofing neither to let music be heard from outside, nor to let the exterior noise enter the hall/room. By designing these building typologies, both room acoustics and building acoustics principles are very crucial. Kang [32] defineed spaces without a special listening function, such as shopping malls or eating establishments, as non-acoustic spaces. Still, these spaces are occupied by users, and there are several studies about the acoustics of these spaces. Especially schools and hospitals are very commonly studied in terms of acoustic comfort. Houses are one of the typologies where we spend most of our time inside. The acoustic comfort in houses depends mostly on the sound transmission loss of building elements and on the room acoustics parameters (e.g. reverberation time) inside the rooms. Limit values for these have been set by standards and regulations [33]. Still, there is an effort to improve these standards especially for the highly annoyed and highly sleep disturbed population [34].

In the guide "Design for the mind - Neurodiversity and the built environment", the need for quiet rooms is addressed [22]. It is reported that enclosed quiet rooms and semi-enclosed quieter zones should be available in buildings, when noise becomes intolerable [22]. Especially in open offices, acoustic pods are developed to be a solution to noise and privacy problems. In a paper about noise impact on workers in open-plan office working environments, it was stated that 90% of the participants think that noise in the office environment has a negative impact on work efficiency [35]. "Quiet rooms" are proposed in terms of increasing employee comfort and productivity [36]. There are also quiet or silent rooms in airports, which provide a calm space for users who are sensitive to noise.

#### 3.4.2. Typology Proposals in Literature and Design Guidelines for Individuals with Different Needs

New building typologies can occur with time due to an emerging function or with changing needs of users due to the changes in daily life. For instance, in a study, a new typology called launch park was proposed for swimming races, regarding spatial coastal use [37]. As another typology, co-housing occurred due to mutual needs of users. In a study where integrated living spaces for elderly individuals are analyzed, this specific function is presented as a typology [38]. Also, design guidelines for individuals with different needs are studied. For instance, a spatial program for an independent living center design was proposed based on mentally different individuals' properties [39] and the design parameters were set [40]. Another study presents the changes that families apply in houses due to problems children with autism have in their home environment [41]. It is mentioned that sound insulation is important for individuals with autism. In the book called "Designing for Autism Spectrum Disorders", recommendations about spatial design issues are listed [42]. There are studies to find out the environmental barriers for people with autism spectrum disorder and recommendations for inclusive design strategies for the built environment [43], [44]. Concerning hearing issues, there is also a study about accessible home environments for deaf and hard-of-hearing individuals which focuses on supplementary AR, AI, and IoT technologies [45].

## 4. A Typology Proposal: Silent House

### 4.1. Design Strategies for the Proposed Typology

It has been observed that the term silent house is often preferred in architectural literature in situations that evoke calmness, architectural simplicity and serenity, rather than being used directly in its literal meaning. Silent house, quiet house, quiet home and tranquil house are common names given to many housing projects. In this study, a new typology called "silent house" for pain hyperacusis patients is proposed and an architectural design guideline for this typology is presented. Silent is used as a term with its literal meaning; a house without noise, where necessary building acoustics and room acoustics principles are applied to architectural design.

In literature, there are several reports and studies with recommendations for making houses quiet [46], [47], [48]. If a silent house is needed, it should be decided whether it is going to be designed and built from scratch or considered as an improvement of an existing building. In both cases, it is possible to achieve sufficient sound insulation, but it is generally easier to start from scratch instead of trying to find and correct all the problematic parts of the existing building. Certainly, the decision may depend on the budget. Thus, both the ideal solution and the alternatives will be presented in this study.

#### 4.1.1. Upper-Scale Decisions

The general approach in noise control studies is to stop the noise at the source, or not to create the noise at all. Before trying to solve noise problems by the receiver, i.e. on building facades, the sound source itself should be controlled. For instance, the motor noise and the wheel noise are the predominant parts of traffic noise. Electric motors produce less noise compared to diesel engines and the dominant use of electric cars would lower the total traffic noise. For the tire noise, noise-reducing road surfaces like silent asphalt can be applied on the roads and low-noise tires can be used. These recommendations are all upper-scale improvements which can be applied by governments or municipalities. Also, in case of a noisy entertainment facility, not the neighboring buildings but the entertainment facility itself should first take precautions against noise, e.g. take the music volume down. When it comes to silent houses, having respectful and understanding neighbors is a matter of chance, as they will be one of the main noise sources.

The importance of quiet areas in Europe was first recognized by the 2002 Environmental Noise Directive [49]. Further research has been done on quiet areas [50], [51], [52] and strategies about quietness have been developed [53]. On an upper scale, by starting a silent house project, it should firstly be decided if the house is going to be in a quiet or noisy environment. A rural area would be an advantageous place to choose for a silent house, as there would be less urban and traffic noise. If there is no chance to settle down in a village or small town, then an area in the city should be looked for with the least noise possible. The need for quietness in urban environments is studied in a research paper and it was found that the need for quietness is strongly related to noise sensitivity [54]. It was also stated that creating quiet places and enhancing possibilities for quiet recreation in urban environments have positive effects on the quality of city life [54].

When designing a silent house, the building plot should not face a busy road, and it should not be near an airport, railway, stadium, market square, open-air entertainment center or industrial building, if possible. Once the building zone is determined, the shape of the building mass becomes a design decision. The most appropriate approach in terms of noise is to position the building so that the shortest side of the building mass faces the noise source, i.e. traffic road. The mass should be arranged in such a way that it prevents traffic noise reflections. Concave mass forms facing busy roads should be avoided. Sound barriers between the road and the building should be provided, if necessary. Also, if the city development plan allows, it would be appropriate to position the buildings in a courtyard arrangement to protect users against transportation noise.

The decision to plan an attached or detached building schema is an important stage of the design process for silent houses. Detached houses have the advantage of not shared walls or floors with neighbors. They also have no structural connections to neighbors and therefore no flanking transmissions. Another important decision is whether the building is going to be a single-story house or a house with multiple floors. A single-story house would be more convenient as a silent house, as it would directly eliminate man-made noise from upper or lower floors. The precautions for multi-story houses and attached houses will be given in the following sections.

#### 4.1.2. Plan and Section Scheme Recommendations

On plan and section layouts, indoor spaces should be classified in terms of noisiness and noise sensitivity. Noise-sensitive spaces should be positioned away from noise sources and appropriate interior planning should be carried out by separating noisy spaces with buffer zones like storage. Rooms should be arranged so that noisy spaces are not adjacent to noise-sensitive functions. For instance, bedrooms as noise-sensitive functions should preferably not be adjacent to mechanical rooms as functions with high-noisiness. In building noise regulations [55], recommendations [56], actions [57] and standards about dwellings [33], [58]; classifications, limit values and required precautions for various room adjacency arrangements are stated. For a silent house, class A sound insulation should be aimed amongst for the six classes for dwellings, class A being the highest and class F the lowest.

Bedrooms and living rooms should be positioned on the quiet side of the mass and not face the main road. Functions like bathroom and kitchen can be located on the busy facade instead. Still, in the case of a silent house, the existence of a busy road next to the building is problematic and should be avoided. Between adjacent flats, furniture such as cabinets and bookshelves placed along shared walls helps reduce airborne noise transmission. Also, spaces with similar noise levels in different flats can be placed symmetrically to each other. In case of multi-story houses, elevators should not be placed adjacent to noise-sensitive functions like bedrooms. A silent house in a multi-story building would require an elevator with regular maintenance for noise and vibration control, or there should be no elevator in the building at all.

It should be noted that all rooms in a silent house are noise-sensitive by definition and by their users' nature, but the time spent in the rooms determines the degree of sensitivity and the priority of protection. The bedrooms are where users are open to any noise threat while they are sleeping. Thus, top priority should be given to bedrooms while taking precautions. Also living rooms are amongst the rooms where most of the time is spent in a house and should be protected accordingly.

#### 4.1.3. Material and Layer Recommendations

A detached and single-story house is the most compact and least problematic form of the silent house typology. With the presumption of being able to control the sound environment of the household, the precautions taken against interior noises may be less in this type of houses. Most of the precautions against noise will be taken at the building envelope, mainly on the facade against exterior sounds like traffic noise. Also, noise control for mechanical equipment is an important issue in these buildings. For airborne sound insulation, the main principles to increase the sound transmission loss for the building elements, especially walls, can be summarized as such: Layered walls with high surface density should be designed (i.e. solid parts should be thick and have high material density), there should be an air cavity between the layers with the possible maximum distance, and this gap should be filled with a porous absorber like rockwool. Leaving some of the gaps between layers blank rather than filling them all in will lead to better results. It should be noted that connection between layers should be flexible and gaps causing sound transmission must be avoided. Both exterior and interior walls can be treated with the same principles.

On the exterior walls, windows and doors should be placed on quiet facades, if possible. Two separate windows with an air gap between them would have a positive effect on facade sound insulation. It is better to maximize the air gap between the windows and to use triple-glazed windows with acoustic lamination. Also, heavy doors should be preferred. Especially for the bedrooms, two heavy doors with an air gap between them would increase the total sound transmission loss. Airtightness for both windows and doors must be ensured with a sealant.

In attached and multi-story buildings, all the precautions taken in the detached and single-story houses are valid. Additional architectural acts for noise control should be taken especially against neighbor noises in these buildings. Television noise is one of the main problems in apartment buildings for hyperacusis patients, as everyone watches TV and it is considered to be normal to leave the TV on during the day. As electronic sounds can cause pain for pain hyperacusis patients [7], they might have to leave the house, if there is not sufficient sound insulation against that noise. It is usually not enough to take precautions just on the walls, as sound can be transferred through the structural system and other building elements. Thus, a holistic approach to soundproofing in silent houses is needed.

In order to make a room soundproof, noise from all possible directions must be eliminated. This room-in-room approach requires noise control strategies for walls, floors and ceilings, to prevent flanking transmissions. For the ceilings, suspended ceilings with flexible connections are recommended. The suspended ceiling should be heavy and there should be an air gap between the ceiling and the suspended ceiling, preferably supported by a porous absorber inside, as recommended also for the layered walls. For the floors, a floating floor where the new screed is disconnected from the existing floor and structural system with a flexible material, is recommended. The disconnection can be achieved with the elasticity of the inserted material, like cork sheets or neoprene footings. The contact of the new screed and the side walls should also be avoided with flexible materials to prevent sound bridges through rigid connections. Covering the floors with a soft material like carpets to reduce the impact noise would also lower the total sound level inside.

Recommendations above were made about the subject of building acoustics, to improve the sound transmission loss of the building elements. In terms of room acoustics, there is no limit value of reverberation times for the rooms in houses [58], but it can be said that house interiors are not expected to be too absorptive or too reflective. In a regulation, 0.5 seconds for bedrooms, 0.8 seconds for living rooms and kitchens, and 1.2 seconds for circulation areas are set as limit values for reverberation times [55].

#### 4.1.4. Recommendations regarding Houseware, Appliances and Mechanical Installations

Pain hyperacusis patients often benefit from closed captions while watching movies or during online meetings, where additional written information is provided, as patients might be unable to listen to electronic sounds [7]. In order to prevent vibration and low frequency noise, external air conditioning units should be mounted with flexible connection materials, away from the windows. The openings created by pipes and channels in building elements should be closed with flexible materials. Use of silent pipes is recommended. Absorptive materials should be used in ducts to reduce the sound level. Noise should be reduced at the source by using mechanical equipment with a lower noise level. Washing machines should preferably be placed in cabinets with doors to further reduce the noise level.

### 4.2. A Case Study of a Silent House: Barbaros House

#### 4.2.1. Acoustic Design Decisions

In this research, acoustic measurements were done in Barbaros House as a case study of a silent house typology. Barbaros House is a single-story detached house, built and designed for a pain hyperacusis patient, with a gross area of 83 square meters. It is located in a small village [59] and does not face any traffic roads. One of the main upper-scale design decisions before the start of the construction was to find a plot where cars were not the main noise source for the building. As mentioned previously, villages are advantageous places for silent houses. The decision to design a single-story house was taken in order to eliminate upstairs noise and it was built as a detached house, which eliminated neighbor noises from adjacent rooms. Still, the building had to be protected against environmental noise, village entertainment noises like outdoor weddings and noise from neighboring plots. Thus, most of the precautions against noise had to be taken on the exterior walls. The floor plan of the case study building can be seen in Figure 1.

As mentioned previously, building elements should be heavy and layered, in order to reduce noise. Barbaros House has natural stone and exposed concrete as facade materials (Figure 2), which have again other layers behind them. Both stone and concrete are heavy materials. As the most noise-sensitive room in the house, the master bedroom was determined. On the exterior walls of that bedroom, precautions were taken against noise. The exposed concrete facade belongs to this bedroom.

Concrete walls have the advantages of being monobloc structures. The layers of the bedroom's exterior wall consist of 25 cm concrete, 5 cm rockwool with an 8 cm air gap, 13.5 cm brick and 3.5 cm interior rendering and plastering mortar in total. The bedroom has two windows (Figure 3) and two doors, to ensure soundproofing. The interior window is a triple-glazed window with acoustic lamination, and the exterior one is a double-glazed window. Both of these windows' structures are made of PVC systems and there is 25 cm of an air gap between them, which helps increase the total sound reduction. Both of the doors are heavy and have proper sealing materials around them without any sound gaps. There is a 28 cm air cavity between the doors. On the ground, there is also a floating floor in this bedroom.

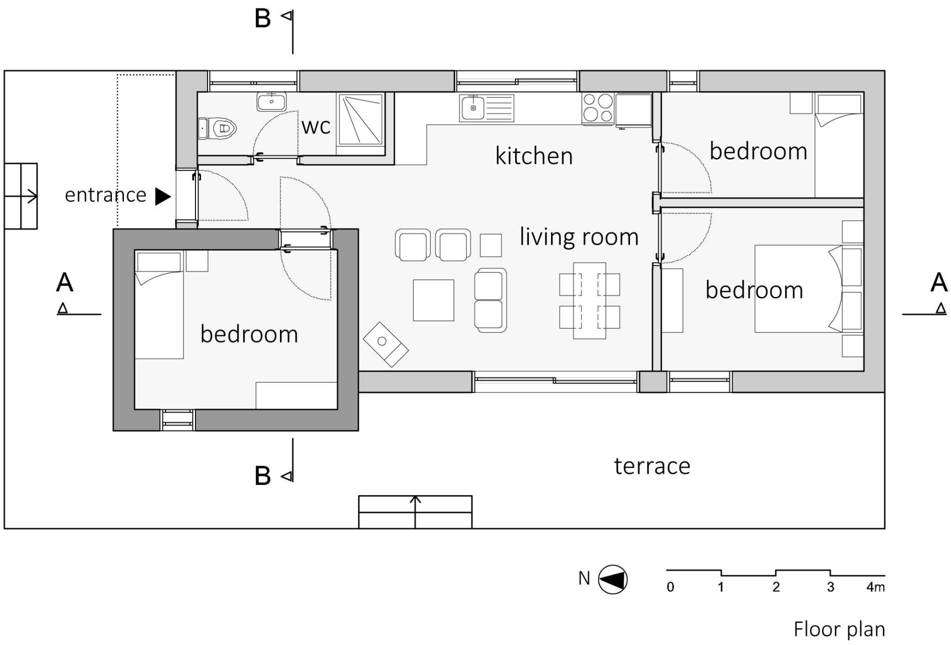


**Figure 1.** Floor plan of the silent house case study building

**Figure 2.** Stone and exposed concrete facades of the case study building

**Figure 3.** Construction phases of double windows

### 4.2.2. Measurement Equipment

Acoustic measurements are done with an omni-directional source (Brüel & Kjaer – Omni Power 4292), a microphone, a power amplifier (Brüel & Kjaer – 2716) and a sound level meter (Brüel & Kjaer – 2260 Investigator). The results are transferred through the software Brüel & Kjaer - Qualifier 7830 to a computer and converted into a table. The height of the microphone was set to 1.5 m above the floor of the receiving room, as stated in the standard [60]. Measurement equipment can be seen in Figure 4.

**Figure 4.** Omni-directional loudspeaker in front of the facade

### 4.2.3. Measurement Results

The frequency range was set to 100 - 5000 Hz on the sound level meter. For each 1/3 octave band frequency, $D_{ls,2m,nT}$ values were calculated as described in ISO 16283-3 [60]. As there is no traffic or busy road in front of the case study building, global loudspeaker method was preferred instead of global road traffic method. In order to calculate $D_{ls,2m,nT}$ sound insulation values, the average outdoor sound pressure levels at a distance of 2 m in front of the facade ($L_{1,2m}$) were measured. Sound pressure levels ($L_2$) were measured inside the receiver room (the bedroom with the concrete facade) and corrections related to background noise levels (BNL) were made. Reverberation times (RT) of the receiver room were measured for each 1/3 octave band frequency and average values of these measurements were taken. From these measurement values, $D_{ls,2m,nT}$ values for each 1/3 octave band frequency were calculated (Table 2) and given in Figure 5. The single-number quantity $D_{ls,2m,nT,w}$ (C; $C_{tr}$) was calculated as 54 (-1; -3) dB, using 1/3 octave band frequency values, as described in ISO 717-1 [61].

**Table 2.** Measurement values

| **Freq. [Hz]** | **$L_{1,2m}$ [dB]** | **$L_2$ [dB]** | **BNL [dB]** | **RT [s]** | **$D_{ls,2m,nT}$ [dB]** |
|---|---|---|---|---|---|
| **100** | 75,06 | 26,23 | 3,64 | 0,52 | 49,00 |
| **125** | 72,47 | 30,94 | 6,08 | 0,38 | 40,34 |
| **160** | 78,09 | 28,99 | 4,94 | 0,41 | 48,24 |
| **200** | 74,98 | 28,08 | 1,38 | 0,40 | 45,93 |
| **250** | 74,86 | 25,51 | 1,01 | 0,50 | 49,35 |
| **315** | 77,80 | 30,02 | 1,46 | 0,49 | 47,69 |
| **400** | 75,68 | 24,36 | 0,95 | 0,39 | 50,24 |
| **500** | 73,11 | 26,99 | 0,68 | 0,35 | 44,57 |
| **630** | 72,65 | 22,44 | 0,96 | 0,37 | 48,90 |
| **800** | 74,85 | 19,92 | 1,67 | 0,39 | 53,85 |
| **1000** | 75,13 | 19,07 | 2,06 | 0,39 | 54,98 |
| **1250** | 76,41 | 18,77 | 3,94 | 0,39 | 56,56 |
| **1600** | 80,61 | 19,30 | 3,62 | 0,41 | 60,45 |
| **2000** | 79,71 | 19,02 | 4,18 | 0,43 | 60,03 |
| **2500** | 81,37 | 16,41 | 5,16 | 0,41 | 64,10 |
| **3150** | 84,94 | 15,95 | 6,06 | 0,39 | 68,38 |
| **4000** | 79,23 | 11,69 | 7,00 | 0,40 | 67,87 |
| **5000** | 76,52 | 10,90 | 8,08 | 0,40 | 65,95 |

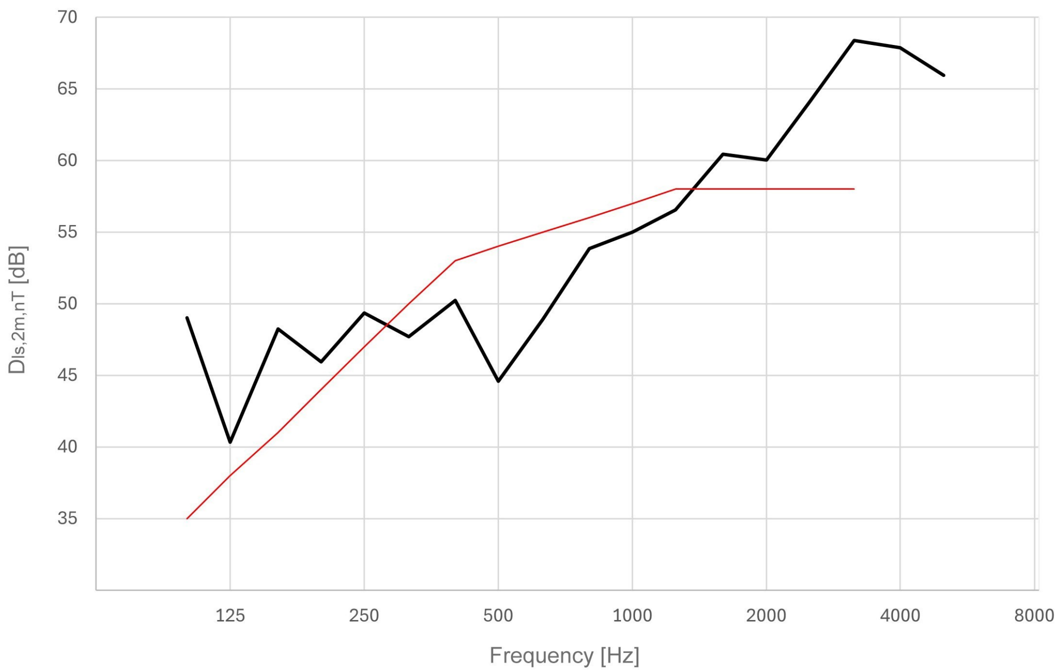


**Figure 5.** $D_{ls,2m,nT}$ values for each 1/3 octave band frequency

# 5. Conclusions

## 5.1. Findings and Discussion

As for now, there are no common successful medical treatment methods for pain hyperacusis. Until there are future developments in medicine regarding pain hyperacusis treatments, the most effective method is self-protection from sound for the well-being of the patient. This study addresses a research gap regarding architectural approaches for the silent needs of patients with pain hyperacusis. The proposed silent house typology is the spatial organization regarding this solution. Single-story and detached houses in village environments are ideal for silent house typology. The case study presented in this article meets the requirements of a silent house, as documented with necessary acoustic measurements, where $D_{ls,2m,nT,w}$ (C; $C_{tr}$) was measured as 54 (-1; -3) dB. Also, in multi-story and attached houses in urban settings, if previously mentioned precautions (layered and heavy walls, floating floors, suspended ceilings, flexible connections, etc.) are taken, silent houses sufficient enough for pain hyperacusis patients can be created.

## 5.2. Limitations

In this study, after the guidelines for silent houses were stated, a single case study building could be measured and documented, as there are no multiple examples of silent houses yet. The term pain hyperacusis has been used for only ten years in literature (Table 1) and there is still a need for medical research to understand its working mechanisms. Still, it is clear that pain hyperacusis patients benefit from silence. In terms of scientific architectural approach, the number of the houses which represent the proposed typology could be increased, but the financial issues while building a new structure can cause limitations.

Also, as the built examples were limited to a single house, there was no chance of a comparative study. Thus, a questionnaire study could not be conducted, which was another limitation of this study.

Emergency response complications and psychological effects of being isolated from noise at home were not evaluated in this study, as the main research problem was to define the architectural properties of a silent house. Still, the security, communication, cultural and psychological aspects of this research are limited.

## 5.3. Future Work

If the number of built examples increases, multi-site studies and comparative analyses including questionnaires and patient interviews will be conducted as future research. Including cost-benefit analyses in future studies would also provide valuable data for pain hyperacusis patients who aim to use and apply the silent house typology for themselves.

Also, conducting systematic evaluation through questionnaire-based studies and field measurements to assess security vulnerabilities due to reduced environmental awareness, emergency response complications and psychological impacts of sensory deprivation in silent houses can be next steps of this research.

Silent houses are designed to provide quiet spaces for sound-sensitive users, but patients need also noise-free public spaces when they go out of their homes. Thus, policies regarding quiet urban areas, quiet offices, quiet transportation, quiet healthcare and quiet markets for hypersensitive individuals should be worked on in the future.

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