Chapter 14

BUILDING DESIGN FOR THE HARD OF HEARING

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ABSTRACT

Great strides have been made in recent decades to make buildings more accessible to the disabled. These improvements, although laudable, apply mostly to those whose handicap is visually apparent. Much more could be done for those with impairments which cannot be seen - the hard of hearing. People who have trouble hearing will often avoid situations that might embarrass them, for example a party in a loud room. In this sense, the built environment can act as a barrier to their integration with society. In most forms of verbal communication, a room and its natural acoustics is the channel between the talker and the listener. Some rooms are better than others. Good building design policy could easily encourage a design environment that is sensitive to the needs of the hard of hearing. This need not imply extra costs to a building, rather a re-focusing of design objectives encouraged by awareness programs and building code improvements. In this chapter, some of the challenges that buildings can impart to the hard of hearing will be presented and explained. Potential solutions will then be discussed.

INTRODUCTION

Building design can and does have an impact on the hard-of-hearing. Unbeknownst to most, acoustical design is now a mature and reliable science, as witnessed by the many successful concert halls built in the last quarter century. But this design knowledge, which could be so easily applied to the benefit of those with hearing difficulties, seldom is – if ever. The hard of hearing population have trouble with speech discrimination. In a noisy environment or an overly reverberant room, they have trouble picking out the words from the rest of the confusion. Intelligent building design can limit both of these problems.

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In most parts of the world – certainly in the industrialised part of the world – local building codes require designers to accommodate the physically challenged in a myriad of ways. The concept of a "Barrier Free" building is now ubiquitous in construction. It's a concept of accessibility for all. Everyone should have a fair chance at enjoying the benefits of our built environment – without any barriers to that enjoyment. Wheelchair ramps, lifts and the like are obvious Barrier Free examples. The rewards of this policy are less obvious but no less cogent. Soon after it was formed in the 1960s, Wright State University in Dayton, Ohio, USA began to pursue a Barrier Free building philosophy, long before the idea made it into building codes. Walking the campus, one is first struck by the number of students with some form of physical challenge. Then, not long afterwards, comes the painful realization that before Barrier Free buildings, these people simply could not obtain a university education. Surely the Barrier Free ethos is good policy. Currently, however, the Barrier Free concept applies to those who are seen as handicapped. It could, and perhaps should, apply to those whose challenges can't be seen but are no less challenging.

With one exception, Barrier Free building codes do not yet extend to the hard of hearing. The exception being places of assembly in new buildings, for example a lecture hall, theatre or, in some jurisdictions, even a classroom. Most building codes dictate electronic hearing assist systems. These systems broadcast signals locally that can be picked up by the patrons' or students' hearing aids. Beyond that requirement – albeit an important one – building codes offer little other advantage to the hard of hearing. As a result, modern building design does not respond to their needs in the ways that it could. If a distilled version of the knowledge required to build a concert hall or opera house could be applied to a classroom, a lecture hall or, for that matter, any other room where people gather for social interaction, the hard of hearing of the next generation could reap the benefits afforded to the wheelchair bound community of today.

Let us first define the challenges that the hard of hearing might face in the built environment and then address how policy makers and designers might respond to those needs.

Perception of Sound in a Room

The Lombard Effect

Some rooms are louder than others. A natural response to a loud room is to speak louder in it. Everybody does this. The natural inclination of human communication is to speak loud enough to be heard. Thus, in a loud room, for example a room with mostly hard surfaces, the first conversation will begin at a louder than normal level. A second conversation will have to talk louder than that, the third even louder, and so on until one has to shout to be understood. We have all experienced this: it is something called the Lombard Effect [1]. As mentioned, the hard of hearing have trouble functioning in a noisy environment; with or without hearing aids. Many might want to avoid the embarrassment this situation would present them, so they do– and in so doing, cut off a normal mode of social interaction available to all others but themselves. A loud room which encourages the onset of the Lombard Effect is not a Barrier Free room for the hard of hearing. A properly designed room can avoid this problem.

We have all been to social gatherings, for example a party or perhaps a restaurant, where it was so loud that it was hard to understand anyone. This problem is exacerbated for the hard of hearing. We have also been to gatherings that might have the same amount of people but everything was fine. It was not too loud and conversations were easy to understand. The difference between the two gatherings is the room in which they were held. In the first example, the empty room was too loud to start with. When people started to gather, the Lombard Effect took hold of the crowd, the speech levels went up and soon enough, people had to shout to be understood. In the second example, the room was a naturally quieter environment. The Lombard Effect never materialised and conversation remained pleasant. The difference between the two examples was the room and, by inference, the decisions made by the room designers. We shall discuss, below, how these decisions might be more sensitively considered.

The Cocktail Party Effect

The Cocktail Party Effect [2] is often confused with the Lombard Effect – perhaps for obvious reasons! The two are not the same. People with normal hearing in both ears (so-called binaural hearing) can hear things that others cannot. An obvious test of audibility of a given sound, for example a sentence, is whether or not it is louder than other sounds that you might hear at the same time: a kettle boiling in the kitchen, a train going by or perhaps someone else's sentence heard at the same time as the one you want to hear. If it is going to be audible, it must be louder than anything else. That makes sense. It turns out, however, that our hearing perception is smarter than that.

With a pair of normal hearing ears people can pick out sounds that are actually quieter than the babble of noise surrounding the sound they want to hear. This is called the Cocktail Party Effect but it does not matter if you're trying to converse at a party in a crowded room or trying to pick out the sound of the cello in the orchestra at other end of a concert hall. Binaural hearing (i.e. hearing with two ears) initiates a neural process that can localise on the sound we want to hear and filter out the unwanted sound to provide cognition. One of the early researchers [3] made a comparison between a radio and our brain. Like a radio we receive a wide range of different signals but in the brain there is a form of audio filter that allows us to select which channel we want to listen to.

An example of sound without the advantage of the Cocktail Party Effect is a monaural recording of a conversation, i.e. on a single microphone recording device. Without the advantage of binaural hearing and, by extension, the Cocktail Party Effect, all the extraneous noise in the room becomes immediately apparent on the recording and conversations are much more difficult to understand. Think of the Nixon tapes in a Watergate documentary. Most of them can't be understood without subtitles.

Monaural (or single ear) hearing is not the only thing to compromise the Cocktail Party Effect. Loud rooms and hearing impairment can also defeat the Cocktail Party Effect.

Many of the hard of hearing have to operate without the advantage of the Cocktail Party Effect. For them, the sound of a large, loud gathering can be as bad as the sound on the monaural recording device (e.g. the Nixon tapes). Even for the normal hearing population, the Cocktail Party Effect can be negated at overly loud levels. Prudent building design can prevent at least part of this problem. A room designed to be naturally quiet will prevent the onset of the Lombard Effect (i.e. people shouting over one another to be heard) and thus prevent the need for the Cocktail Party Effect (i.e. trying to hear someone when everyone else is speaking louder).

Speech Intelligibility

So far we have been talking about communication over the distance of a few metres at most; conversational speech in a restaurant or at a party. The challenges at larger distances are more acute. For good speech intelligibility beyond a few metres two fundamental criteria must be satisfied; (i) the reflected sound that arrives at the ear within 50 milliseconds (1/20 of a second) must be louder that the sound that arrives after 50 milliseconds, (ii) the word or sentence that someone is trying to understand must be twice as loud (+10 dB) as other sounds that might interfere with it. We thus have the concept of so called Useful and Detrimental sound. For normal hearing listeners, the threshold between useful and detrimental sound is 50 milliseconds. For the hard of hearing it is shorter than this, probably in the range of 35 milliseconds or less. In short, for good speech intelligibility, the sound coming from the speaker and the first one or two reflections must be louder than anything else [Figure 14.1].

These discoveries were made as researchers were trying to build better theatres and concert halls but they apply equally to any space where people need to understand speech; a subway, a classroom, a cinema, a political rally. It would be very difficult for anyone to make it through their day where these fundamental concepts of communication between humans do not apply.

Multi-Modal Perception

In recent years, researchers have discovered that the understanding and appreciation of sound is a so-called multi-modal percept. That is, the neural process interpreting a sound employs both visual and aural stimuli. Other senses behave the same way; smell can influence taste, for example. Lip-reading has long been known to improve speech intelligibility – in both normal and hearing-impaired listeners. Other visual stimuli have a more nuanced influence on the appreciation of sound but they are, nonetheless, still important.

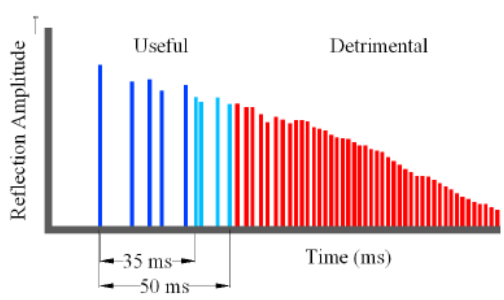

Figure 14.1. For good speech intelligibility early reflections are useful and late reflections are detrimental. For the hard of hearing, the threshold between the two is shorter, about 35 milliseconds (ms) rather than 50 ms.

A long held credo for good acoustical design has been that "good sightlines make good sound lines". The reasoning is simple, if the head in front of a listener in a lecture hall is blocking the path between the talker and the listener's eyes; it's probably blocking the sound path between the talker and the listener's ears as well. What was not fully appreciated before, however, was what the listener sees plays a role in what he or she can hear.

Prudent building policy and design directives should respond to this. With one exception, good sightlines in a lecture hall or any other place of assembly are not currently mandated by building codes – but they could be. Ironically, the single exception is for patrons in wheelchairs. Surely, the advantage afforded to that sector of the population can be extended to the hearing-impaired.

Good sight lines can be achieved either by raising the talker on a platform or raising the seats towards the back of the audience. Often, both methods are employed simultaneously. A good designer will also stagger the seats from one row to the next, making sure that a listener is positioned between the two people in front. Another strategy or directive for classrooms would be to ensure that hearing-impaired students are seated at the front of the room with a clear line of sight to the teacher. This implies, by the way, a "front end" layout of the classroom where teachers are always facing the students.

Parenthetically, insofar as design policy is concerned, it would be advantageous to take a lesson from the nascent "green" building movement. Follow-up surveys have found that the way people use a green building is just as important as its design, perhaps more so. People using a room that, unbeknownst to them, has been designed to take advantage of natural light will, without thinking, flip on the light switch. They don't need to consume unneeded energy, and they probably wouldn't if someone had explained it to them. The problem is: nobody did. Likewise, in a room that might be used by the hard of hearing – the classic case being a classroom – the teachers need to be informed on how to use the room to its best advantage and to the best advantage of their students.

ACOUSTIC PROPERTIES OF ROOMS

Reverberation

There are two components of any sound heard in a room, the direct sound coming straight from the sound source and the reflected or "reverberant" sound that has bounced off the different surfaces in the room; the walls, the floor and the ceiling. The direct sound terminates instantaneously after the sound source ceases. The reverberant sound will persist. The length of reverberant decay will depend on the room and the fittings inside it and is quantified by something known as the "reverberation time". In a small living room with soft furniture it could be as short as 0.25 seconds. In a large cathedral or atrium with hard surfaces, it could be as long as 8 or 9 seconds. The hard of hearing have trouble understanding speech in a highly reverberant space.

Reverberation times can be easily and reliably predicted. The reverberation time of a room is proportional to its enclosed volume and inversely proportional to the amount of acoustic absorption in the room (i.e. soft materials). So, if a room is too reverberant and it already exists, it is difficult to change the size (volume) but the reverberation time can be reduced by adding soft, acoustically absorbent materials. Conversely, if the room has not yet been built and the designers still have control over the volume but cannot use soft materials (e.g. a hospital room that must be kept clean), the reverberation time can be limited by keeping the volume small.

Some sounds benefit from reverberation, for example classical or choral music. Other sounds are often inhibited by reverberation. The reverberation in a large church or cathedral is an important embellishment to the sound of the organ or the choir but it makes speech difficult to understand. The more reverberation there is, the more difficult it is to understand speech. For the hard of hearing, this problem is exacerbated. For example, in America, the American National Standards Institute (ANSI) permits a maximum reverberation time of 0.6 to 0.7 seconds in a classroom. For the hard of hearing, research has found that it should be shorter, in the range of 0.4 to 0.5 seconds [4].

Loudness

As noted above, some rooms are louder than others. How does this happen and how can it be controlled? Three components control the natural loudness of sound in a room; the room's size (volume), its reverberation time and the distance between the sound source and the listener. Loudness is proportional to reverberation time and inversely proportional to both volume and distance. This simple concept – only reliably codified in the 1980s – makes sense on an intuitive level. Lively, reverberant rooms are louder than soft, non-reverberant rooms. Large rooms typically are not as loud as small rooms and, of course, the further away a sound is, the less loud it is.

So, once again, how is this applied in building design? In this example, consider a dining room in a home for senior citizens, many of whom might be hard of hearing. If the room is too loud, as public dining rooms can often be, normal hearing diners are going to have trouble understanding conversations, hard of hearing diners even more so. The designers of the room have three options to work with:

1 Distance, keep the diners close to each other; providing small tables for 4, maybe 5 people; avoiding large round tables for 10 or 12.
2 Keep the reverberation time short, i.e. include a lot of soft materials in the room. Placing carpet in a dining room can create health and maintenance issues and is therefore not a practical design option.
3 The ceiling should be soft and acoustically absorbent as should finishes on the walls.

Consider also the Lombard Effect, the situation where everyone is trying to talk louder than each other. In the dining room or, for that matter, any other room where speech is used, the Lombard Effect is initiated by the natural loudness of the room. Remember that people naturally respond to a loud room by speaking louder. The way to prevent the onset of the Lombard Effect is to control the room's natural loudness, and that is done by either making the room bigger (increase the volume) or making the materials softer (increase the acoustic absorption).

Ventilation Noise

Heating, ventilation and air conditioning (HVAC) systems are never noticed until they stop working, that is if the room is too hot or too cold. Ventilation noise, likewise, is one of those sounds that is never noticed until it is too loud. In almost all buildings, it forms the background or ambient noise that is ubiquitous but, if quiet enough, rarely ever noticed. The problem is in the grey area between where it really is quiet and where it is so loud that people complain. It is this grey area that affects speech intelligibility, more so for the hard of hearing. In this section we shall consider a room type where designers currently pay scant attention to ventilation noise, a classroom. Studies have shown that classrooms rarely satisfy the guidelines for normal hearing students, let alone the hard of hearing population. One study, in the early 1980s [5] found that classroom noise alone accounted for 50% to 75% of the variance of reading delays of one year or more in elementary school students – and that was for a normal hearing population. A more recent study has shown that hard of hearing children need to hear a word three times more frequently than a normal hearing child before that word can enter his or her lexicon [6,7].

Remember that to be understood, speech sounds must be heard at levels that are twice as loud (i.e. +10 dB) as any other sound. In a room, "any other sound" often means the ventilation system. Studies have shown that hearing-impaired need speech levels that should be at least 15 dB louder than other sounds [5]. This is true even when people are wearing their hearing aids. Modern hearing aids can distinguish between speech and noise – a very complex neural process – but only to a certain extent. So, for example, imagine a classroom with a noisy ventilation system and a teacher who is not talking loudly enough. The signal-to-noise ratio (i.e. how much louder the speech is than the ventilation noise) could easily be less than the 10 to 12 dB required by normal hearing students. A modern hearing aid can separate speech from noise to improve things but the improvement is limited to about 5 dB. The hearing aid cannot eliminate all of the ventilation noise. The result is a signal-to-noise ratio that is still often less than the 10 to 12dB that a normal hearing person requires.

Classrooms or other places of assembly for the hard of hearing need quiet ventilation systems. Recent studies have suggested levels in the range of 30 to 35 dBA[1] [4]. To achieve ventilation noise levels as low as these, an acoustical specialist will probably be required on the architectural design team – something that is rarely done. Low ventilation sound is especially important for the most challenged students, those in elementary school, the youngest of which are still forming language skills. There are some simple design practices that will help ventilation systems achieve this level of quietness. If the building has a central ventilation plant, recognise that this will probably be the noisiest room in the building. Classrooms should not be above, below or beside it; they should be separated across the corridor from the central plant. The plant should be located over washrooms, not classrooms. If the ventilation system is based on packaged air handling units located on the roof, these should not be located above a classroom. They should be positioned over an adjacent corridor or, preferably even further away, perhaps over a storage room. Air velocities should not be too fast, otherwise a hissing turbulence induced noise will be generated. Velocities should not exceed 2.3 meters per second (450 feet per minute).

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[1] In the Heating Ventilation and Air Conditioning (HVAC) industry, background noise levels are quantified with a series of Noise Criteria (NC) curves. 30 to 35 dBA is about the equivalent of NC-20 to NC-25.

In the situation of an existing classroom, where it may not be possible to quieten the ventilation systems, teachers should use microphones. A typical application would have a teacher wearing a lapel microphone, which is then amplified through loudspeakers or, more likely, amplified then broadcast to the students' hearing aids.

Electronic Solutions

Buildings are no longer made of just bricks and mortar. Electrical systems, information technology (IT) and electronic communication play an increasingly important role in building design. Most of the hearing-impaired community wear hearing aids. As mentioned above, however, hearing aids aren't always the perfect solution, notably when speech is presented in a noisy environment. The solution, in that scenario, is to move the microphone closer to the talker. The microphone in a hearing aid could be 20 to 30 metres away from a talker. A microphone on a podium or on a lapel could be 200 to 300 mm away. Shortening the connection between the talker's microphone and the listener's hearing aid can be easily facilitated these days with electronic broadcasting systems. There are two popular systems; FM and infrared. Both have their advantages and disadvantages. Infrared systems usually sound better but require a line of sight between the transmitter and the hearing aid. FM systems don't require a line of sight but can have interference problems with other FM signals. FM systems are not appropriate in a building that might have privacy concerns as it is easy to eavesdrop on them.

In many jurisdictions these days, these so called Hearing Assist systems are required for "places of assembly" that seat 200 or more. A place of assembly is a lecture hall, theatre, concert hall, etc. Hearing Assist systems can, however, benefit other rooms, notably classrooms, as discussed above. If a school board cannot afford to install Hearing Assist systems in all of their classrooms, they can supply personal systems tuned to a broadcast frequency that a given student's hearing aid can receive. Hearing Assist systems can also be beneficial in residential buildings. A system, installed in the home, can allow hearing-impaired members of the family to hear voices coming from other rooms where they otherwise would not have the advantage of lip-reading. An FM system is required in this situation; infrared systems based on a line of sight broadcast will not work.

Public Address (PA) systems are another means of improving speech intelligibility but, again, the needs of the hard of hearing imply stricter guidelines when they are integrated into the building design. Remember that for good speech intelligibility, the useful early sound (i.e. direct plus 1 or 2 reflections) must be louder than the late detrimental sound and that the total sound must be twice as loud (+10 dB) as other sounds. The latter requirement is easily achieved by simply turning up the volume on the PA system. But that, in itself, is not always sufficient. Take the example of a subway or metro station, typically very reverberant rooms. A reverberant room has a lot of detrimental late reflections bouncing around. Sometimes these can be reduced with soft materials but these are difficult to keep clean and, over the years, form a build up of iron dust from the braking steel wheels. One solution is; rather than decrease the late detrimental energy, increase the useful early energy. This can be very easily done by increasing the number of loudspeakers on the platform. That way wherever a patron might stand, he or she is getting more early energy that late. Maximum distances between loudspeakers and listeners are in the range of 3 m for a normally hearing patron, slightly shorter for the hard of hearing. This implies that ceiling mounted speakers may not be a good option as they will be too far away. Speakers on the walls or, perhaps, hanging from the ceiling will work better.

Finally, staying with the example of a subway or metro, it is important to understand that the chain of hearing between a talker and a listener is as only as good as its weakest link. Good microphones and good annunciation are as important as anything else mentioned above. It is unlikely that the average train operator speaking from his cab into a telephone receiver will ever be understood in the rest of the car. Transit systems should have a centralised system of announcements where a train operator can call in, then have his or her message given by a trained speaker, into a good microphone in a quiet recording room or booth.

Examples such as this occur in all sorts of rooms where announcements might be made. In some cases, access to a trained speaker might not be available, for example on an airplane. Recognise however that video screens can be found in most public spaces these days. These combined with voice to text software could provide the hard of hearing with the visual cues they require.

CONCLUSION

The architectural design profession is a progressively minded, innovative community. Historically, they embraced the early 20th century concerns with fire protection. The conflagrations of London in the 17th century and Chicago in the late 19th century are unlikely to ever happen again. Building codes dictate against practices that would lead to conflagrations and, during building design, the code rules. Likewise, in the late 20th and early 21st century, both building code and other socially responsible guidelines have led to Barrier Free buildings that benefit not just the physically challenged but all of us.

Barrier Free building design requirements do not, however, currently extend to the hard of hearing. They could, very easily – and they should.

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