

Implications

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Acoustics of Green Buildings

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The need to design and construct environmentally friendly and sustainable buildings has had a great impact on the design of all building types. In addition to increasing the energy efficiency of buildings, “green” building design philosophies also have impacted design through better material resource management, the use of renewable energies, and consideration of the indoor environmental quality (IEQ) of the building. Modern building designers have begun to understand the benefits of IEQ (e.g., thermal comfort, improved air quality, improved lighting, better access to daylight) and strive to incorporate them in green building designs. The Leadership in Energy and Environmental Design (LEED®) rating system incorporates IEQ as a major part of the rating systems for all building types.

One design aspect of the indoor environment that continues to be a problem is acoustics. With the exception of LEED for Schools and LEED for Healthcare, acoustics is not considered in the LEED rating systems. This article outlines some of the major acoustic problems in the built environment and the inherent conflict between some green

building design techniques and acoustics. Recommendations for improving acoustics in green buildings are provided.

How Do We Know Acoustics Are a Problem?

The first step necessary to improve acoustical performance in buildings is acknowledging that a problem exists. Post-occupancy evaluation (POE) surveys can help identify the problem. POEs are increasingly being used by building designers to judge the efficacy of their designs. The Center for the Built Environment (CBE) at U.C. Berkeley, among others, has been developing a database of POE surveys for commercial buildings for over a decade (CBE, 2009). In 2006, the database contained useful acoustic data for over 181 buildings from over 23,000 respondents that were analyzed by researchers at the CBE (Abbaszadeh, Zagreus, Lehrer, & Huizenga, 2006). The 181 buildings were a mixture of old and new (recently renovated or new construction) with 21 of the buildings designated as “green.” Figure 1 shows the results of satisfaction with buildings’ IEQ aspects across the 181 POE surveys.

The survey results show that among non-green buildings, occupants were dissatisfied with both thermal comfort



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and acoustics and were slightly more dissatisfied with acoustics. Occupants were slightly satisfied with air quality and highly satisfied with lighting quality and the overall building quality. In green buildings, satisfaction with thermal comfort, air quality, and overall building quality increased greatly; lighting quality essentially stayed the same; and acoustic quality declined slightly. While the building performance of most IEQ variables in green buildings showed improvement or stayed the same as non-green buildings, acoustics were poor in non-green buildings and stayed poor in green buildings.

The survey also included more in-depth questions about the different IEQ categories. Figure 2 shows a breakdown of the complaints related to acoustics. The majority of acoustic problems in green buildings were related to speech and telephone intrusion between occupants. Additionally, office equipment noise and outdoor noise complaints were slightly higher in green buildings.

Acoustic Complaints

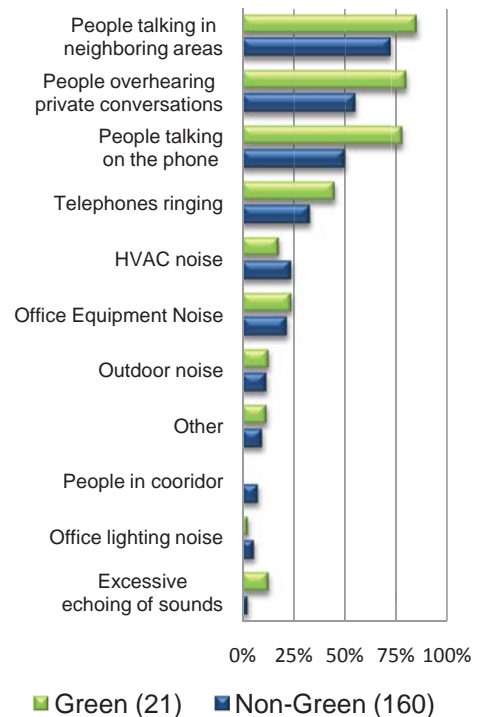


Figure 2: Acoustic complaints as seen in CBE's POE database. Green buildings show a pronounced lack of sound isolation between occupants, resulting in a lack of speech privacy.

IEQ Satisfaction

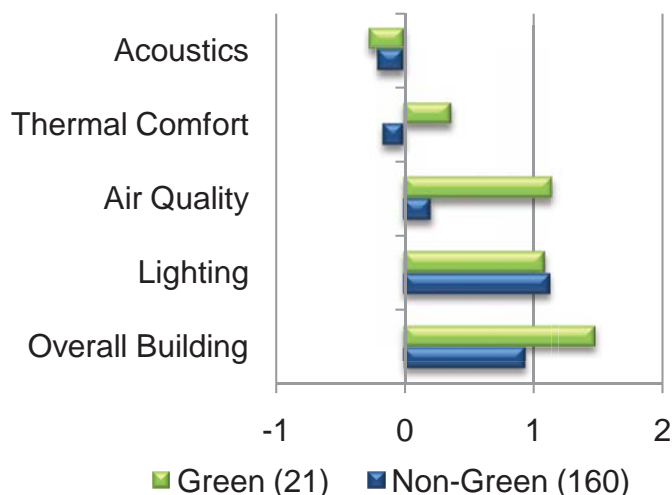


Figure 1: Environmental satisfaction results from CBE's POE survey. More positive numbers indicate greater satisfaction and more negative numbers indicate greater dissatisfaction. Results show that occupants are dissatisfied with the acoustics of green buildings.

Types of Acoustical Problems

Acoustical problems in buildings usually break down into one of three main categories: excessive noise, lack of speech privacy, and lack of speech clarity. Each is discussed below.

Excessive Noise

Excessive noise occurs when the background noise level itself is too high. This could be caused from exterior noise being transmitted into the building, noise from other rooms and/or building equipment being transmitted into occupied rooms, or noise being generated by other building occupants. In many cases, the problem of excessive noise is really a problem of poor sound isolation, i.e., noise from various sources not being segregated from building

occupants. Excessive noise may not pose a health threat, but perceived noise levels have been linked to reductions in occupant performance (Ryherd & Wang, 2008). Excessive noise is controlled by reducing the noise level of the sources, reducing the transmission of noise from sources to the occupants, or both.

Speech Privacy

Speech privacy is the extent to which speech is unintelligible to the unintended listener. This is primarily related to the difference between the level of speech at a given location and the background noise level at that same location. While buildings with poor sound isolation can cause both excessive background noise and poor speech privacy, a building with poor speech privacy may not have an excessive noise problem. Indeed, the worst speech privacy typically exists when background noise levels are extremely low but speech levels remain high such as in open office areas. Poor speech privacy is especially an issue in courtrooms, hospitals, clinics, and in the offices of the doctors and lawyers where inadequate speech privacy is a legal issue (e.g., HIPAA) as well as an occupant satisfaction issue. Speech privacy is usually controlled by reducing the ratio of speech-to-noise energy (SNR). This can be accomplished by either reducing the speech energy transmitted to the unintended listener, increasing the background noise experienced by the intended listener, or both.

Speech Clarity

Finally, a lack of speech clarity occurs when the acoustics of a room deteriorate the acoustic communication channel creating communication problems. While this could be an obvious problem in classrooms and lecture halls, it is also a problem within many other spaces including conference rooms, medical facilities, retail spaces, restaurants, and office lobbies. This problem can be caused, in part, by excessive background noise, but also can be caused by excessive reverberation, which is the

repetitive reflection of sound from room surfaces. Reverberation is controlled with the addition and careful placement of acoustic absorbing and/or diffusing materials on room surfaces. When two high reflecting surfaces are parallel to each other, a very annoying acoustic defect called a “flutter” echo can be created. Flutter echoes are particularly annoying and detrimental to speech clarity and should be avoided.

Acoustical Issues in Green Buildings

Now that some of the major acoustic problems in buildings are understood, the question remains as to why they are worse in green buildings. One of the main reasons is that the design techniques that are utilized in green buildings to improve energy efficiency, sustainability, and other IEQ aspects of buildings tend to exacerbate acoustic defects. Often design team members are simply not aware of the impact of their design decisions on the acoustics of the building (Hodgson, 2008). Three of these design decisions are discussed in more detail below: increased use of glass, use of natural ventilation, and removal of acoustic absorbing surfaces.

Use of Glass

Utilizing daylight to reduce electric lighting energy and to improve lighting quality requires a greater number of windows in the building enclosure and, often times, the use of interior glass partitions. Interior glass partitions help transmit daylight further into buildings but also lead to decreased sound isolation between interior spaces. The use of glass in the building enclosure is often driven by a desire to maximize views of the outdoors and improve the architectural aesthetic. Unfortunately, windows and glass partitions have significantly lower sound isolating capabilities than the opaque wall and roof elements they are replacing. “Acoustical” glass products do exist, but they tend to be very highly priced and do not have the acoustic isolating capabilities of opaque elements.

An additional problem with the increased use of glass is the fact that glass has very low acoustic absorption and when used for daylighting and views, cannot be covered with an acoustic absorbing material. As a result, reverberation can be significant in rooms with large amounts of glass leading to speech privacy and speech clarity issues. Furthermore, the increased use of daylighting has led to an increased transmission of outdoor noise to the building's interior, significantly problematic in noisy urban environments or near high-speed traffic highways, railways, or airports.

The conflict between the use of glass for daylighting and the acoustic problems glass creates cannot be avoided. However, many building designs use extreme amounts of glass for architectural purposes, far beyond what is necessary for views and daylighting (Figure 3). A more careful design of the building enclosure can minimize the amount of required glass and still provide the desired amount of daylight and outdoor views by replacing some glass with more conventional solid wall construction (not simply using spandrel glass). The remaining opaque sections of the enclosure must then be carefully designed to provide very high sound isolation to help compensate for the poor sound isolation of the glass that has been used.

The minimization of glass as a building component has additional benefits including initial cost (glass is an expensive building material), ongoing costs (glass is expensive to maintain), and sustainability (while glass can be completely recycled, most vision glass has little recycled content and the creation of glass utilizes a great deal of energy). Recently, optically-transparent acoustic absorbers have been developed. While they are expensive, they can be used to reduce reverberation in environments where large amounts of glass are used and other approaches are insufficient to control reverberation or flutter echo.



Figure 3: Example of a building with very large amounts of glass that likely has poor outdoor/indoor sound isolation. (Photo Copyright 2009 by idan586 and made available under an Attribution-Share Alike 2.0 license. <http://www.flickr.com/photos/idan586/3552909176>)

Natural Ventilation

To reduce ventilation system energy use and construction costs and to increase the fraction of outdoor air supplied to occupants, many building designers reduce the amount of mechanical ventilation and increase the use of natural ventilation. Natural ventilation uses wind pressure and thermal stack effect to drive airflow through building openings (Figure 4). For this to work there needs to be openings in the building enclosure and limited use of partitions so that air can flow nearly unimpeded.

Buildings designed to use natural ventilation can result in three negative acoustic impacts: more and larger penetrations between the interior and exterior environments, increased use of open-office designs with lower partitions on cubicles, and ventilation connections between isolated spaces. These design changes can result in decreased exterior-to-interior sound isolation and decreased interior sound isolation between workers, which can create problems with background noise and speech privacy. However, it should be noted that the use of natural ventilation

systems can result in significantly reduced mechanical system noise generation that can be beneficial unless it results in decreased speech privacy.

Again there can be a direct conflict between designing buildings for increased natural ventilation performance and good acoustic performance. The use of carefully-designed acoustic baffles on air inlets and the use of full-height partition walls with acoustic louvers and baffles can help improve sound isolation, with only a small cost in natural ventilation performance (Hodgson, Khaleghi, Richter, & Razavi, 2009). When sound isolation from outdoor noise or between office work spaces is a major concern in the building, the use of mechanical ventilation systems should be used instead of natural ventilation. Speech privacy can be increased with the careful use of speech masking systems that introduce specially designed background noise into a room with loudspeakers and a signal generator. Such systems should only be used when other means of sound isolation between workspaces such as physical walls or high partitions are not feasible.

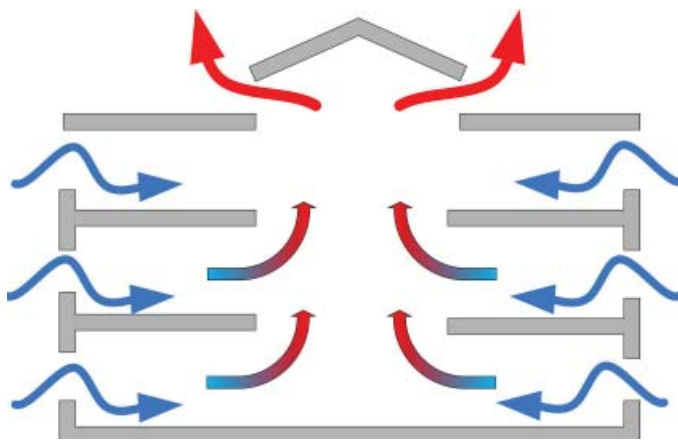


Figure 4: Natural ventilation uses wind pressure and thermal stack effect to drive airflow through building openings.

Sound Absorbing Surfaces

A final problem is the trend away from use of sound absorbing surfaces and surface coverings to a greater number of hard, reflecting surfaces in rooms. There are a multitude of reasons for these design changes including the use of exposed concrete surfaces to utilize thermal mass and/or radiant heating and cooling for better thermal control and reduced energy use; reduced use of dropped ceilings with increased use of natural ventilation and suspended lighting systems; and reduced use of acoustic ceiling tiles, carpeting, and fabric wall-coverings for maintenance and air quality reasons. All these changes lead to a decreased quantity of acoustic absorbing materials in rooms.

The most important of these changes is the reduced use of acoustic ceilings. Acoustic ceilings typically provide the majority of acoustic absorption in the rooms in which they are installed; they also significantly reduce the acoustic ceiling reflection between workspaces in open office designs. When ceiling absorbers are removed, the ceiling reflection significantly reduces sound isolation between the occupants' work areas. Besides decreases in sound isolation, the reduction in absorption increases the overall noise levels from office equipment and increases reverberation in the room, both of which are documented problems in green buildings.

The solution to this problem is quite simple: acoustic absorbers must be restored to the room. In particular, ceiling absorption, either in the form of acoustic ceiling tile or spray-on acoustic absorbers is highly recommended. Ceiling absorption reduces reverberation and increases sound isolation between the occupants' work areas. When ceiling absorbers cannot be installed, wall-mounted absorbing panels are recommended. Where radiant heaters and coolers or exposed thermal masses are required, perforated

heat exchangers with integral sound absorbing materials are recommended. It should be noted that the installation of carpeting on the floor significantly reduces the floor noise generated by office occupants, but provides little overall acoustic absorption.

Final Thoughts

Green buildings are a growing part of the building industry and, in general, they provide better IEQ and sustainability than their conventionally-designed counterparts. However, the acoustics of most green buildings are decidedly worse. Among the reasons are the increased use of glass, increased use of natural ventilation, and reduced amount of acoustic absorbers. Careful and coordinated design can help to ensure that acoustics are considered in the design process. However, all members of the design team need to be aware of and agree with the need for good acoustics to ensure that acoustic needs are maintained throughout the design process, an integral aspect of IEQ.



Figure 5: This open office environment in Minnetonka, MN, seeking LEED®-EBOM platinum certification, incorporates a significant amount of glass, high ceilings, and low partitions between work areas.

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