EDITORIAL

Haunted Buildings and Other Acoustical Challenges

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Sir Isaac Newton's famous motto *I do not invent hypotheses* (or *I do not promote infeasible systems*) is applicable to most specialists. The slogan *I do not make haunted buildings* (or *I do not design buildings with noise and vibration problems*) should be a bylaw of contemporary architects. To successfully implement this principle, architects should consult acoustical and vibration engineers. Noise and vibration 'ghosts' in buildings can be induced by internal and external operating machinery and even by good neighbors.

The Case of a Haunted Building

Many tales have been told of haunted houses – doors exploding off the hinges, lights spinning on their own, inexplicable sounds of a crying woman or heavy footsteps.

But some stories are real. At the end of the 19th century, a devious contractor hired a team of workers to build a rental building in Moscow, Russia. After the building had been completed, the rogue took advantage of the verbal agreement with the workers (they were illiterate) and paid them just half of what had been promised. In response to their protest, he called the police and made the workers improve the roof just for food and vodka.

However, tenants did not stay long in the new building because of a mysterious nocturnal roaring, the 'haunted' house did not provide sufficient rental income and creditors appeared with written contracts in hand. The contractor tried to 'fix' the problem using illegal methods but finally went to prison. The new owner, a railroad engineer, hired the workers who had built the house to eliminate the source of the evil noise. They showed him the empty vodka bottles revengefully embedded in the roof and loft with the open necks outward. The air in the bottles resonated and 'wailed' when a strong wind blew across the open necks.

Using a Helmholtz resonator model, the engineer evaluated the frequency of this noise as about 100 Hz. This low-frequency sound penetrated into the rooms through the ceiling and windows. During the day, the 'ghost' roaring was partly masked by the street noise, but the local winds were strong at night. Such a nocturnal noise, both tonal and intermittent, proved too annoying even for those tenants who did not believe in poltergeists. After the cheerful workers removed the glass 'ghosts,' the rental house became profitable.

Mechanical and Electrical 'Ghosts'

Multistory commercial and residential buildings contain a variety of mechanical and electrical devices (fans, compressors, pumps, vents, pipes, elevators, and transformers) that may create noise and vibration problems. Even if mounted on proper vibration isolators, rotating machinery can briefly excite unwanted resonances through walls and floors on its transition from one operating speed to another. In areas near machinery rooms, bottles on desks and books on bookshelves may tremble like they might under a low-magnitude earthquake.

This is very similar to what allegedly happens in 'haunted' houses. The causes of some 'ghost' phenomena can be quite sophisticated. For instance, if two supply fans operate in parallel (that is, they blow air into the same duct) and have the rotational speeds N_1 and N_2 rpm, the nonlinear interaction of the two airflows results in a sound wave with a 'difference' frequency of $f = (N_1 - N_2)/60$ Hz. For example, if $N_1 = 1700$ rpm and $N_2 = 1520$ rpm, a difference frequency of $f = 3$ Hz will be generated. If the fundamental natural frequency of the air volume in the duct coincides with this difference frequency, the resonance inflicts extensive vibration to the duct walls and to the building structures supporting the duct. Most noise and vibration problems associated with building equipment are linear but in any case, operating machines should be isolated from quiet areas of a building. The simplest method is to separate machine rooms from offices and apartments with as much space as possible. Otherwise, placing a noise sensitive space next to a working machine requires high noise reduction.

Room in a Room – a Ghost Cage

If a noisy machine is close to quiet areas, an extra enclosure should be constructed around the operating equipment inside the machine room. Such a "room in a room" is not just a double-walled system. Generally speaking, it is a synergetic combination of sound-insulating and sound-absorbing techniques. The floor of the internal room is structurally separated from the internal walls and adjacent floor slabs. The ventilation system includes silencers. Room in a room structures work well for test laboratories located close to conference rooms.

One such system was implemented at a company developing racing engines. The 'racing' people were very satisfied with this accomplishment and used to show it to their guests. After a meeting in a conference room on the second floor, unaware visitors were invited to see the "ghost in a cage" downstairs. Through the window of a control room, the surprised guests observed a powerful racing engine roaring just 10 ft below the floor of the quiet conference room.

Infrasound Ghosts

Sometimes a noise problem originates within the head of the person complaining. A sensation of a ringing or roaring noise in our ears is called tinnitus. In many cases, outside noise sources are to blame. The issue of noise pollution from wind turbines is one of the frequent complaints, although proponents of wind turbines deny that there is a problem. However, measurements indicate that wind turbines generate a notable amount of infrasound or low-frequency sound. Another outside source of 'mysterious' vibration and noise can be subways. Trains, airplanes, and trucks are easily identified, and their noises are more irritating than frightening.

Involuntary Ghosts

Good neighbors do not enjoy rock music with their windows fully open and do not have noisy parties late at night. However, the following stories show that even good neighbors sometimes turn their dwellings into 'haunted' houses. In both cases, those complaining were elderly women living in multistory residential buildings. The ghost was a noise allegedly coming from an upper-floor apartment.

The first case happened to a colleague of mine. The complainant lived on the second floor. A chronic low-frequency noise occurred from 9:00 a.m. to 6:00 p.m. while the third-floor neighbor was not at home. My colleague visited the neighbor on the forth floor. She was a typist working at home. The vibration from her mechanical typewriter was conveyed through the desk to the linoleum floor, and the thin linoleum layer was not a good isolator of low-frequency vibrations. All the floor slabs and the internal and external walls were similar concrete

panels. The fundamental frequency of the bending vibration for such panels was calculated to be about 60 Hz, which was consistent with the spectrum measured at the apartment on the second floor. The typist willingly agreed to have rubber isolators placed under her desk and the 'ghost' problem was solved to the satisfaction of all parties.

The other story involved a woman complaining of TV noise. The woman called on her neighbor but found his TV to not be excessively loud. So, she suggested that the ghost noise could be emanating from another apartment – but from which one? At her landlord's request, I visited an upper apartment. A young Ph.D. student had recently moved in with his mattress, TV set, computer and many books – all resting on the floor. I had previously measured the airborne sound transmission loss of the concrete floor in two opposite directions – with the testing sound source (a loudspeaker) on the floor of the lower room and with the source on the floor of the upper room. In the second case, the sound insulation proved notably worse. We elevated the TV by 1 ft using his books as the supports. This temporary solution worked to some extent and the young man promised to buy a TV table the next day to solve the problem. SV

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