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The Effects of Infrasound on Humans in Living Spaces

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A B S T R A C T

Infrasound, defined as acoustic waves below 20 Hz, has been documented to influence human physiology and perception, yet remains largely absent from architectural discourse. This review synthesizes cross-disciplinary evidence from acoustics, physiology, and environmental psychology to reposition infrasound as a legitimate architectural design concern.. Findings show that everyday building services—compressors, HVAC systems, and ventilation fans—generate persistent low-frequency fields that interact with room geometry, producing localized resonance "hot spots." These amplified zones overlap with resonance ranges of the human body and neural rhythms, contributing to discomfort, fatigue, or subtle cognitive modulation. Evidence remains heterogeneous, and individual sensitivity varies, yet the architectural significance lies in recognizing buildings as resonant systems that can unintentionally sustain infrasonic fields. The study advocates integrating low-frequency awareness into design workflows, service placement, room proportioning, and post-occupancy evaluations, reframing infrasound as a spatial and environmental variable within salutogenic and evidence-based architecture.

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1. Introduction

This manuscript was initially motivated by three cases: "The Ghost in the Machine" (Tandy&Lawrence, 1998), later sensationalised as a 'ghost story', putting paranormal etiquette to infrasound; and the historical recollection of the infamous works of Victor Gavreau, later linked to patents for infrasonic weapons, which cast infrasound into the realm of fear and conspiracy. These accounts show how low-frequency resonance can provoke uncanny bodily and perceptual effects, but they remained framed outside architecture (Bowdler, 2018); the third case mentioned in this introduction connects all of the sensory experiences mentioned in the first two, through an architectural lens, by measuring the infrasound and the dimensions of the cellar where the eerie sensations were documented (Tandy, 2000).This recognition revealed that architecture itself can sustain and amplify infrasonic fields and is, in

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fact, a resonant system even for infrasound, providing the impetus to reframe infrasound as an architectural design concern.

While these cases are often cited in anecdotal or paranormal contexts, they are used here solely to illustrate measurable acoustic phenomena relevant to architectural environments. Despite documented physiological and psychological effects, architecture has rarely treated infrasound as a design concern, leaving a significant gap in architectural design.

In 1998, Vic Tandy and Tony R. Lawrence published the article “The Ghost in the Machine” in the Journal of the Society for Psychical Research, describing unusual sensations of dread, uneasiness and eerie “ghostly” presence observed in a laboratory environment. Although such experiences could easily have been interpreted as psychological or even paranormal, further investigation—prompted by the vibrating tin-foil knife on the bench—revealed a physical cause: a newly installed fan in a nearby room was emitting a frequency of approximately 19 Hz. While not clearly perceived as conventional sound, this vibration corresponded to the natural resonant frequency of the human eyeball (NASA, 1978), offering a plausible explanation for the reported visual disturbances in peripheral vision. Such effects are not universal, but they reveal how resonance phenomena can trigger perceptual anomalies in certain individuals. It is important to note that not everyone exposed to this specific frequency would necessarily experience such sensations; visual disturbance remains an individual occurrence, prompted when the eyeball itself begins to vibrate.

A strikingly similar case occurred two decades earlier involving Vladimir Gavreau, a scientist at the Centre National de la Recherche Scientifique (CNRS) in Marseille. During the mid-1960s, Gavreau’s team experienced unexplained nausea, disorientation, and ear pressure in their concrete laboratory building. The source was identified as a faulty ventilator in a neighbouring facility emitting infrasound at ~7 Hz. As recounted by Bowdler (2018), the symptoms vanished once the ventilator was deactivated. This incident subsequently motivated experimental work on infrasonic generation and its possible biological effects. Subsequent studies have confirmed that whole-body resonance occurs between 3–8 Hz (NASA, 1978), while the vestibular apparatus is most sensitive to 7 Hz. Such disruptions may lead to significant vertigo and malaise (Stepanov et al., 2003; Evans & Tempest, 1972).

In 2000, Vic Tandy investigated another reported “haunted” space, a 14th-century cellar beneath the Coventry Tourist Information Centre. Visitors from different countries independently reported intense sensations—chills, a strong “presence,” pressure at the threshold, and even seeing a woman’s face—despite no visible stimuli. Having already experienced similar effects in the laboratory in 1998, Tandy sought a physical rather than paranormal explanation. His calculations showed that the cellar’s 7.7 m length supported a standing wave at ~22 Hz, while the connecting corridor resonated at ~16 Hz. Measurements revealed a stable tone around 18.9 Hz with additional peaks near 23 Hz, consistent with predicted room modes. No mechanical source was identified, suggesting that the resonance amplified low-frequency components already present in the ambient noise field (Tandy, 2000).

The measured frequency was almost identical to that observed in the 1998 laboratory case, aligning with ocular resonance (~19 Hz), head resonance (2–20 Hz), and beta brainwave rhythms (15–30 Hz). While beta activity supports logical thinking and focus, its excessive prominence is linked to chronic anxiety and hyper-arousal (Abhang, Gawali, Mehrotra, 2016). This convergence underscores how architectural geometry itself can act as an acoustic system, unintentionally shaping human perception and well-being.

Tandy noted that the recorded non-linear modulation of the 19 Hz signal by a slower 2–4 Hz oscillation mirrors a principle relevant to acoustic disruption: temporally modulated low-frequency rhythms can be more difficult to habituate to than steady tones (Tandy, 2000; Thiel & Alexander, 2000). In animal communication research, nonlinearly modulated and acoustically unpredictable sounds such as fear screams and alarm calls are known to elicit stronger behavioural responses because their irregular structure signals urgency and threat (Blumstein et al., 2014). While this work does not address infrasound directly, it highlights a broader acoustic principle: irregular modulation is more disturbing than steady tones. Military and security research on sonic and infrasonic weapons applies a comparable principle at far higher intensities, using pulsed or modulated acoustic fields to disturb vestibular function, cognition, or bodily comfort (Altmann, 2001; Li et al., 2026).

It is important to note that the sole aesthetic of the cellar's dim lighting, exposed sandstone, and steep stairs may also contribute to what would conventionally be considered an eerie impression. However, Bruno and Pavani stated that the perception actively reaches out instead of just receiving signals. The brain goes looking for stimulation, pulling from sight, sound, and everything in between. It pieces together whatever's available into one fluid experience, blending all the signals into something that feels real (Bruno & Pavani, 2018).

While these cases are often sensationalised in paranormal or weapon narratives, in this review they are referenced solely to illustrate measurable acoustic phenomena relevant to architectural environments. Their anecdotal framing in public discourse does not diminish their value as examples of how resonance can shape perception; however, it does highlight the need for a more systematic architectural perspective.

Taken together, the laboratory, ventilator, and cellar cases illustrate a broader principle: infrasound may undoubtedly be present in architectural spaces. The dispositions and dimensions of the first two sites were not investigated, while the Coventry case highlighted an architectural perspective: spatial geometry can unintentionally amplify or sustain low-frequency vibrations, producing perceptual and physiological responses that are easily misattributed to psychological or paranormal causes. While acoustics and medicine have documented such phenomena, architecture has rarely addressed them as design concerns.

This paper moves beyond anecdotal accounts by systematically synthesizing cross-disciplinary evidence into an architectural framework. This paper's contribution is to reposition infrasound as an architectural design concern by synthesizing cross-disciplinary evidence into implications for building practice. By examining sources of infrasound, the presence or absence of soundwave patterns, and spatial resonance mechanisms, the study highlights how everyday building services and geometries can shape low-frequency sound fields. In doing so, it bridges acoustics, physiology, and environmental psychology with architectural design, advancing salutogenic and evidence-based approaches to occupant well-being.

2. Theoretical Background

Sound is a mechanical vibration that propagates through a medium (Yost, 2006) and is conventionally divided by frequency into infrasound, audio-frequency sound, and ultrasound. Infrasound refers to acoustic waves below 20 Hz; audio-frequency sound spans 20–20,000 Hz; ultrasound exceeds 20,000 Hz (ISO, 1995; Health Protection Agency, 2010). Standard hearing-threshold curves such as ISO 226:2003 are defined only above 20 Hz for "otologically normal young adults

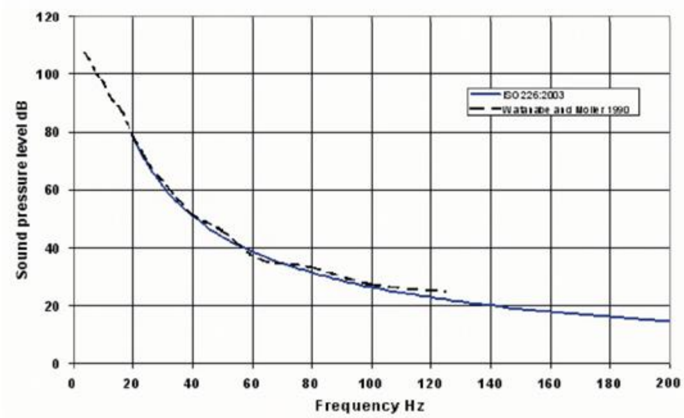

Figure 1. Comparison of hearing threshold curves and age-related hearing loss statistics (Moyano & Lezcano, 2020).

The solid line above 20 Hz represents the ISO 226:2003 standard threshold; the dashed curve (4–125 Hz) is from Watanabe and Møller (1990). The overlap is nearly perfect, with the main difference being that the ISO standard line does not depict the frequencies under 20 Hz and their possible audibility, whereas Watanabe and Møller (1990) do argue that lower frequencies may be heard if the SPL level is high (above 80 dB for 20 Hz, and around 100 Hz for around 10 Hz, as observed in the figure 1).

Infrasound is characterized by longer sound waves in comparison to higher-frequency sounds (Leventhall, 2003). Attenuation of sound waves in air is increased by the square of its frequency. As frequencies get lower, the attenuation also gets lower. Ground and other barriers also absorb the sound waves, but attenuation is also progressively lower as the frequencies get lower (Leventhall 2003). In fact, infrasound is characterized by very low absorption in various environments such as air, water and the Earth's crust (Voskoboinick, 2023) due to its long wavelengths, which allow it to diffract around obstacles, penetrate conventional insulation, and travel vast distances with minimal energy loss (Ghadiali & Trivedi, 2015).

Unlike higher-frequency sound, infrasound exhibits low attenuation due to its reduced interaction with particles and surfaces, penetrating conventional insulation more easily, making mitigation more challenging (Johnson, 1976).Conventional sound insulation materials are largely ineffective at infrasonic frequencies; mitigation in this range depends primarily on structural design, mass–spring–mass systems, façade airtightness, and in some experimental cases, metamaterials or tuned resonators, rather than on standard lightweight absorbers (Arjunan et al, 2024).

2.1. Sources of Infrasound

Sources of infrasound are both natural and anthropogenic. Large-scale events such as tsunamis, earthquakes, thunderstorms, volcanic eruptions, offshore storms, and historical explosions (e.g., Krakatoa 1883, the 1908 Siberian meteorite, and the 1945 Hiroshima and Nagasaki bombings) generate powerful infrasonic waves (Berglund et al., 1996; Moyano & González Lezcano, 2022). At lower intensities, sea waves, wind, and ordinary human activities such as running (Johnson, 1975), as well as certain animals including elephants, lions, and whales, produce infrasonic signatures (Voskoboinick, 2023).

Natural infrasound often accompanies visible cues — the rumble of a storm or seismic tremor makes contextual sense. In contrast, anthropogenic infrasound may be experienced without perceptible cause, producing sensations of vibration or pressure that feel uncanny. Contemporary exposures arise primarily from technological sources: industrial installations, low-speed machinery, and household appliances (Berglund et al., 1996; Leventhall, 2007). In buildings, compressors (refrigerators, heat pumps, air conditioning units), ventilation fans, and other rotating machinery generate low-frequency components whenever they operate (Boabaid Neto et al., 2015; Pedersen et al., 2017). Altmann (2001) notes that wind turbines, HVAC systems, and even the aerodynamic effects of opening a car window produce infrasonic levels. Industrial equipment such as crushers, furnaces, and ship engines generates very high intensities, while blast waves form a special case: their positive overpressure peak can be extreme, though the negative phase is bounded by ambient atmospheric pressure (~101 kPa at sea level). Even neighbors contribute to low-frequency exposure, since walls attenuate high frequencies more effectively than very low ones (Leventhall, 2003).

2.2. Psychological and Physiological Effects

Physiological studies show that the human body exhibits distinct resonant frequencies in the infrasonic range: whole-body resonance at approximately 3–8 Hz, head and neck across 2–20 Hz, vestibular sensitivity near 7 Hz, and ocular resonance around 18–19 Hz (NASA, 1977; NASA, 1978; Stepanov et al., 2003). These ranges overlap with intrinsic brain rhythms: delta (0.5–4 Hz), theta (4–8 Hz), alpha (8–12 Hz), sensorimotor rhythm (12–15 Hz), and low beta (15–20 Hz), which support sleep, drowsiness, calm wakefulness, focused relaxation, and alert problem-solving, respectively (Kasprzak, 2012). Experimental EEG work has demonstrated that low-frequency and infrasonic stimulation can suppress alpha activity and modulate SMR and beta rhythms, indicating that neural oscillations can entrain to environmental vibrations even below the threshold of conscious audibility (Kasprzak, 2012; 2014). Kasprzak (2012) summarises the main EEG rhythms and their functional roles (Table 1).

Table 1. Main brainwave types, frequency ranges, and associated functions (Kasprzak, 2012).

Brainwave	Frequency (Hz)	Function
Delta	0.5–4	Deep sleep
Theta	4–8	Drowsiness, daydreaming
Alpha	8–12	Calm wakefulness
SMR	12–15	Focused relaxation, learning
Beta	15–20	Alert thinking, problem-solving

Functional neuroimaging studies point in a similar direction. In a working memory fMRI experiment, Weichenberger et al (2015) found that brief 12 Hz infrasound bursts produced pronounced activation of primary auditory cortex and associated cortical networks, without impairing cognitive performance. A subsequent resting state study reported altered cortical and subcortical connectivity during near-threshold infrasound exposure, indicating that neural activity can be modulated by low-frequency stimulation even when subjective perception is limited (Weichenberger et al., 2017).

Two longitudinal studies conducted by Ascone et al (2021) and Forlim et al (2024) systematically examined the impact of prolonged exposure to airborne infrasound at 6 Hz on brain structure and neural connectivity. The first study showed an extremely significant structural brain change: grey matter volume reductions observed, which are linked to working memory and somatomotor coordination, and in the left angular gyrus, associated with language processing, reading, and auditory integration (Ascone et al., 2021). This is also investigated and confirmed by Berglund et al (1996).

Follow-up study (2024) revealed significant changes in resting-state functional connectivity across key neural networks, all of which are integral to introspection, planning, decision-making, and sensory-motor integration (Ascone et al., 2024). Notably, the auditory network exhibited no measurable activation, reinforcing the hypothesis that infrasound influences the brain via non-auditory neural mechanisms.

Scatterty et al (2026) conducted a controlled experiment in which participants were exposed to calming or unsettling music with an embedded 18 Hz infrasonic component or without it. Participants could not reliably detect the presence of infrasound, yet the infrasound condition was associated with elevated salivary cortisol, increased irritability and disinterest, and a sadder appraisal of the sound environment.

Furthermore, Scatterty et al (2026) note that infrasound appears to evoke irritability and annoyance more reliably than acute anxiety, despite previous common suggestions that infrasound is anxiety-inducing. Across both animal models and human studies, low-frequency exposure is associated with aversive responding, negative appraisal, and elevated stress markers, while self-reported anxiety often remains unchanged. This pattern supports the view that infrasound functions primarily as a subtle environmental irritant or background stressor rather than a classic anxiety-inducing agent, acting on vestibular and limbic pathways in ways that may never fully reach conscious awareness (Scatterty et al., 2026). Together, these findings establish a physiological and acoustic foundation for understanding how infrasonic environments interact with architectural space and human perception.

3. Methodology

This manuscript employs a cross-disciplinary synthesis methodology, reframing established acoustic and physiological evidence through an architectural lens. The approach is analytical and integrative, designed to highlight how infrasound is generated and how it interacts with humans in architectural spaces. Relevant literature was identified through searches in major scholarly databases (Scopus, Web of Science, PubMed, Google Scholar) using combinations of keywords such as infrasound, resonance, architectural acoustics, effects of infrasound, covering publications from the 1960s—when Gavreau's CNRS ventilator case first drew attention to infrasonic effects in buildings—through to 2026.

Studies were included if they were peer-reviewed articles, technical reports, or documented case studies that reported measured acoustic data, while anecdotal or paranormal accounts without measurement were excluded. With two deliberate exceptions, all cited sources are peer reviewed: Gavreau's ventilator incident is treated as a historical case widely cited in later work, and Bowdler (2018) is used only for descriptive detail about the deactivation of the fan; all physiological claims draw on peer-reviewed sources. Selected evidence was then organised into three analytical strands: sources of infrasound (natural and anthropogenic), resonance mechanisms in the human body (ocular, vestibular and whole body resonance, as well as neural entrainment), and architectural factors that amplify or sustain low frequency fields, such as building services and room geometry.

These strands were synthesised into an architectural framing that translates acoustic and physiological findings into design implications, with an emphasis on salutogenic and evidence-based approaches. Finally, physiological resonance ranges were cross-checked against frequencies reported in architectural case studies, and patterns were triangulated across acoustics, physiology, psychology, and architecture to strengthen robustness and clarify where relationships are well supported and where they remain hypothetical. The synthesized process is shown in the diagram in Figure 2.

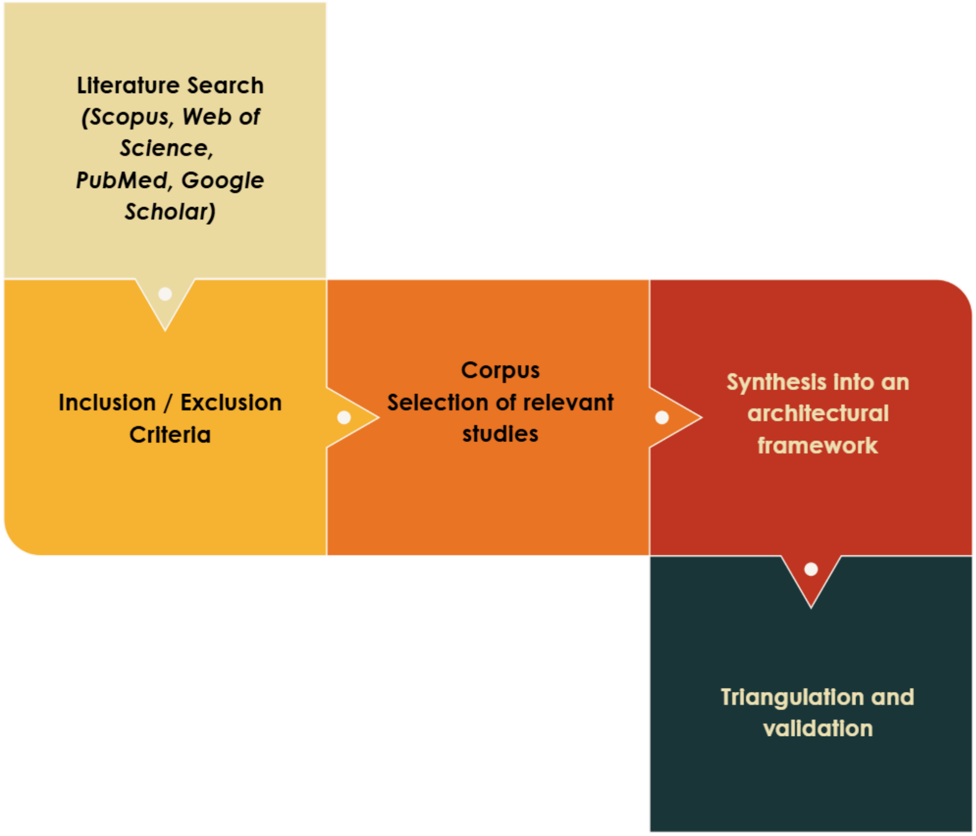

Figure 2. Review Methodology Diagram

The diagram illustrates the cyclical review process. The process begins with a structured literature search across major databases, followed by the application of inclusion and exclusion criteria. Evidence was then organized into four analytical categories—sources of infrasound, wave patterns, resonance mechanisms, and architectural implications. Finally, findings were synthesized into an architectural framework and validated through triangulation across acoustics, physiology, psychology, and architecture.

3.1. Conceptual Framework

This review adopts a stepwise conceptual framework linking infrasound to human experience in architectural space. First, natural infrasound sources are excluded, and anthropogenic sources such as compressors, appliances, ventilation systems, and others that generate low-frequency acoustic energy are defined. Second, this energy forms specific wave patterns that interact with rooms and structures, producing standing waves and spatially uneven low-frequency sound fields. Third, these fields can couple with known resonance ranges of the human body and brain, so that, under certain exposure conditions, infrasound may act as an underlying environmental factor influencing comfort, mood, and well-being rather than as an overtly audible sound.

4. Measurement Limitations in Architectural Context—Problem Statement

Due to the limited exploration of this topic from an architectural perspective, several issues arise. These include the lack of dimensional data for the architecturally defined spaces in which infrasound was measured, as well as the reliance on A-weighted measurements, which are not well suited to accurately assessing infrasound.

Naturally, industrialisation favoured progress and efficiency rather than inaudible soundwaves. Much of the available literature addresses low-frequency noise from roughly 20 to 200 Hz, rather than sub-20 Hz infrasound. The result is an architectural blind spot. Residential complaints may involve spectral content extending toward or into the infrasonic region, but if instruments, standards, and consultants are not tuned to detect it, the phenomenon effectively disappears from professional knowledge. This helps explain why the literature is richer on industrial sources, wind turbines, or laboratory exposures than on ordinary dwellings, even though domestic environments clearly contain persistent low-frequency sources and highly variable indoor transfer conditions.

Routine building-noise assessment still privileges the audible band and frequently relies on A-weighted indices, meaning low-frequency and infrasonic components are easily under-represented or missed entirely. A further consequence is interpretive fragmentation: because direct residential infrasound data are scarce, evidence tends to be split across separate domains — room acoustics without physiology, physiology without architecture, or complaint literature without detailed spectral documentation. One contribution of the present review is therefore to connect these partial literatures into a single explanatory frame centred on the dwelling as an acoustically active environment.

Two examples demonstrate the richness of the inaudible spectrum emitted by refrigerators and cooling compressors, which are commonly overlooked. Boabaid et al (2014) showed that a typical refrigerator does not produce merely a faint "hiss," but a broadband spectrum with pronounced tonal components around 50–60 Hz and significant measurable energy from about 10 Hz upwards (Figure 2). When such tonal low-frequency content is reinforced by room resonance, it can create local "hot spots" of pressure and vibration inside a dwelling, providing a physical basis for occupants' reports of heavy-headedness, headaches, or general discomfort when spending time in those specific zones. These local "hot spots," known as room modes, can amplify certain frequencies by 20–30 dB. When such recordings are compared to hearing thresholds, it becomes clear that specific infrasonic frequencies resonating within enclosed spaces may intrude into the audible range if they are already at a level close to the hearing threshold line.

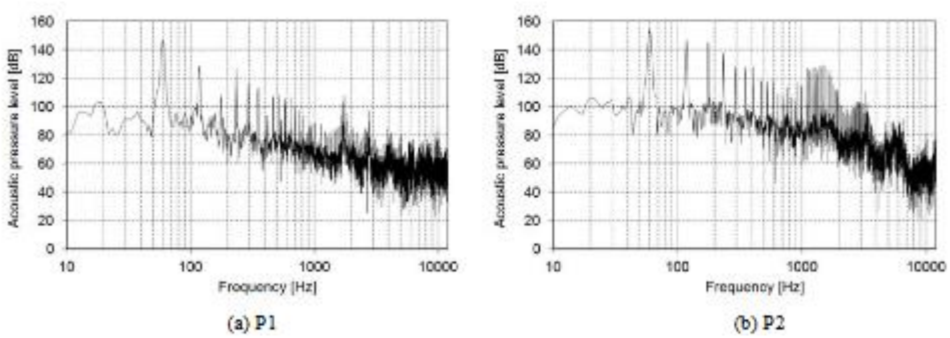

Figure 3. The acoustic pressure spectral density in narrow frequency bands (1.56 Hz), for a typical test under a compressor speed of 3500 rpm (58.3 Hz approximately), (Boabaid et al, 2014).

Pedersen et al (2017) provided a particularly useful spectrogram-based view of how low-frequency complaints manifest in real dwellings. Using an occupant-operated recording device, they documented three cases involving a restaurant cooling compressor, a residential heat pump, and nearby wind turbines. Figure 4 shows a spectrogram of the heat pump recording taken outside the house. The left image presents the full spectrum of the inaudible sound, demonstrating that it is a broadband signal with dominant low-frequency content. In contrast, the right image, weighted according to the hearing threshold, shows that much of this low-frequency energy falls below the range of conscious audibility.

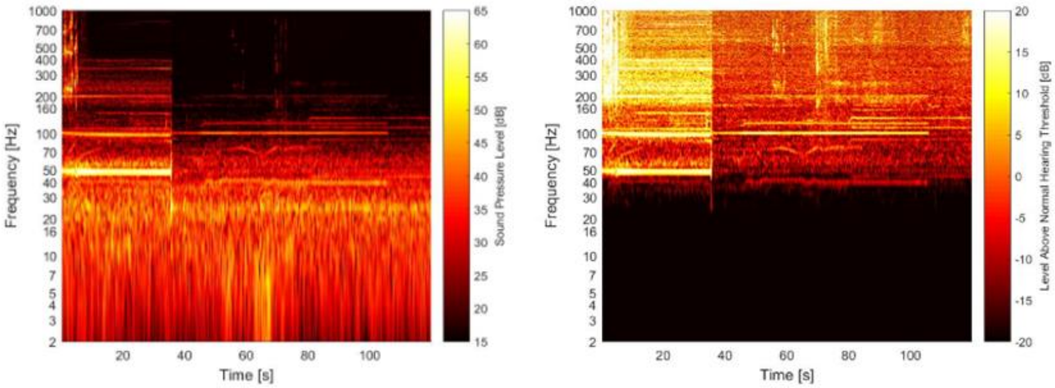

Figure 4. Left: Spectrogram of an outdoor recording. Right: a weighted according to the hearing threshold spectrogram of the same recording, (Pedersen et al., 2017).

5. Research gap and aim

In architecture, sound is omnipresent and routinely considered to ensure acoustic comfort. Standard architectural acoustics, however, primarily focus on the audible spectrum (20 Hz–20 kHz), leaving inaudible soundwaves—particularly infrasound—largely unaddressed. This omission creates a significant research gap: while acoustics and medicine have documented the physiological and psychological effects of infrasound, architecture has rarely treated it as a design concern.

Despite growing evidence that low-frequency and infrasonic sound can modulate perception, mood, and cognitive performance at levels encountered in everyday environments, these phenomena remain absent from architectural standards, design workflows, and post-occupancy evaluations. Existing studies are fragmented across acoustics, medicine, and environmental psychology, offering little guidance on how architects should recognise, anticipate, or mitigate infrasound within real buildings.

Low-level, continuous infrasound generated by household appliances, HVAC systems, and building services can interact with room resonance, producing localized "hot spots" that may incite occupant discomfort. Despite this evidence, architectural practice lacks systematic frameworks for recognizing, measuring, and mitigating such exposures.

This paper aims to raise awareness of infrasound as a legitimate architectural design concern. By synthesizing cross-disciplinary evidence from acoustics, physiology, and environmental psychology, the study develops an architectural framework that connects sources, resonance mechanisms, and occupant responses. In doing so, it advocates for integrating low-frequency awareness into design workflows, advancing salutogenic and evidence-based approaches to healthier built environments.

5.1. Research Significance and Contribution

The significance of this study lies in raising awareness of infrasound as an overlooked architectural factor. While acoustics, physiology, and psychology have documented its effects, architecture has rarely acknowledged infrasound as a design concern. By reframing it as a spatial and environmental variable, this paper contributes to salutogenic and evidence-based architecture. The framework developed here connects everyday sources, resonance mechanisms, and occupant responses, offering architects and researchers conceptual tools to recognise and anticipate low-frequency exposures. In doing so, the study encourages future standards, design workflows, and post-occupancy evaluations to integrate low-frequency awareness, ultimately promoting healthier and more responsive built environments.

6. Case studies

Due to the lack of definite architectural research dealing with the presence of infrasound in dwellings, below is presented only one study measuring both architectural space and infrasound, calculating the relationship of the space with the soundwaves. Pedersen et al.'s (2017) study moves away from A-weighted measurements and contains valuable spectrograms, which show the whole broadband of inaudible frequencies present in dwellings. Oliva et al.'s (2011) study experimentally proves and illustrates how furniture affects the 50 Hz frequency soundwaves. It is important to note that while 50 Hz is audible at appropriate SPL levels is not considered infrasound and is mentioned exclusively for its possible method of use for infrasound mitigation, which calls for further research.

6.1. Architecture as a Resonant System

As mentioned in the introduction, in 2000, Vic Tandy investigated a reported “haunted” space, a 14th-century cellar beneath the Coventry Tourist Information Centre. Visitors from different countries independently reported intense sensations in the Coventry cellar—chills, a strong “presence,” pressure at the threshold, and even seeing a woman’s face—despite no visible stimuli. This prompted Tandy to investigate a physical, rather than paranormal, cause. Building on these accounts, this section shifts the focus from physiological responses to spatial mechanisms, examining architecture itself as an active acoustic system that can unintentionally amplify, trap, or modulate low-frequency energy and thereby intensify such experiences.

The mathematical calculations based on Tandy's cellar geometry showed that its 7.7 m length would support a longitudinal standing wave at about 22 Hz, while the corridor connecting to it (10.95m in length, which would resonate at 16.3 Hz), with an effective straight-line length of roughly 9.5 m, would resonate close to 18 Hz. The plan of the cellar is depicted in Figure 5. Measurements of the space revealed a stable tone around 18.9 Hz with an amplitude of about 38 dB, together with slower 2–3 Hz fluctuations and an additional peak near 23 Hz, consistent with the predicted room modes. No mechanical source could be identified, but the standing wave persisted for several hours. This does not mean that the sound “appeared from nowhere”; rather, the room resonance may have been extracted by amplification of low-frequency components already present in the ambient noise field (Tandy, 2000).

The measured frequency of the recorded soundwave was almost identical to the one measured in the mentioned 1998 Laboratory case (Tandy, 1998). That frequency coincides with the natural frequency of the eyeball, and also falls into the spectrum of the head resonance that is documented to be at around 2-20 Hz (Kroemer, 2008; NASA, 1977). This frequency falls into the spectrum of beta (β) brainwave rhythm as well (15-30 Hz). In optimal conditions, beta waves facilitate logical thinking and conscious focus, yet their prominence triggers a state of high arousal, chronic anxiety, and an inability to relax (Abhang, Gawali, Mehrotra, 2016).

Tandy noted that the 19 Hz signal with a slow 2–4 Hz amplitude modulation and noted that it mirrors a principle relevant to acoustic disruption: temporally modulated low-frequency rhythms can be more difficult to habituate to than steady tones (Tandy, 2000; Thiel & Alexander, 2000). In animal communication research, nonlinear and acoustically unpredictable sounds such as fear screams and alarm calls are known to elicit stronger behavioural responses because their irregular structure signals urgency and threat (Blumstein et al., 2014). Military and security research on sonic and infrasonic weapons applies a comparable principle at far higher intensities, using pulsed or modulated acoustic fields to disturb vestibular function, cognition, or bodily comfort (Altmann, 2001; Li et al., 2026).

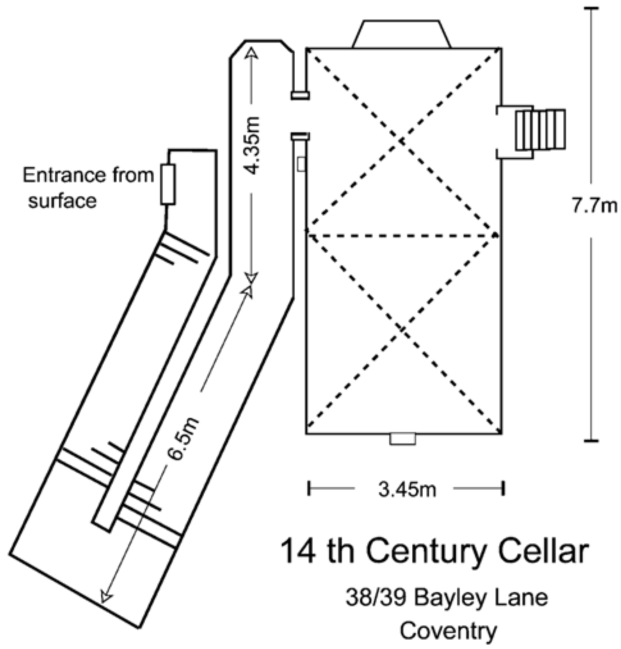

Figure 5. Plan of the cellar (Tandy, 2000).

While infrasound is widely investigated in the military and weapons field, this comparison must be treated carefully. Altmann's prospective assessment explicitly warns that the dramatic potential of infrasonic weapons has often been overstated, and that technically effective deployment at a distance is difficult (Altmann, 2001). The relevance of the weapon literature here is therefore not to suggest that buildings secretly function as weapons, but to underline that temporally modulated low-frequency sound can be physiologically meaningful. If similar waveform structures are present in residential buildings at much lower levels, their relevance to occupant well-being cannot be dismissed outright, even though the exposure context and intensity are entirely different.

As mentioned in the introduction and as observable in Figure 6, the aesthetic of the cellar is reminiscent of those viewed in horror movie scenes and, undoubtedly, might be perceived as 'eerie' itself, even without the presence of infrasound.

Figure 6. The cellar of Coventry Tourist Information Centre (Tandy, 2000).

6.2. Room Resonance: Basic Principles

Room resonance refers to the amplification of sound at specific frequencies, known as room modes (standing waves) within an enclosed space. These frequencies arise from the interaction between a radiating sound source and its reflections within an enclosed room, when the sound wavelengths bear specific proportional relationships to the room's dimensions. Under these conditions, the reflected waves form stable patterns of constructive and destructive interference, creating regions of maximum and minimum sound pressure (Năstașa et al., 2023).

The fundamental relationship between wavelength (λ), frequency (f), and the speed of sound (c) is expressed as:

$$\lambda = c/f$$

Where:

- c is the speed of sound in the medium (the speed of sound through air is approximately 343 m/s at 20°C),
- f is the frequency in Hz. (Leventhall et al., 2003)

To calculate the fundamental room mode along a single axis (e.g., length), the formula becomes:

$$f = c/2L$$

Here, L is the distance between two opposing walls. This expression yields the lowest frequency at which an axial resonance can occur. Higher-order resonances (harmonics) appear at integer multiples of this fundamental frequency (Everest, 2001).

6.3. Harmonics and room mode types

Harmonics are resonant frequencies that occur at integer multiples of the fundamental mode. If a room's fundamental axial mode is 43 Hz, its harmonics will appear at 86 Hz, 129 Hz, and so on. These harmonics interact with room geometry to produce complex acoustic patterns, especially in small or rectangular spaces (Mašović, 2021). Room modes are typically classified as:

- Axial modes: between two parallel surfaces (e.g. floor–ceiling, opposite walls)
- Tangential modes: involving four surfaces
- Oblique modes: involving all six surfaces (Everest et al., 2001)

Axial modes are strongest and most easily calculated, while tangential and oblique modes are weaker but still contribute to the overall sound field. Their harmonic relationships can lead to constructive or destructive interference, affecting clarity, warmth, and spatial perception (Everest, 2001)

In a box-shaped room, resonance frequencies can be estimated from the modal equation:

$$f_{lmn} = \frac{c_0}{2}\left[\left(\frac{l}{L_x}\right)^2 + \left(\frac{m}{L_y}\right)^2 + \left(\frac{n}{L_z}\right)^2\right]^{1/2} \quad l, m, n \geq 0$$

where Lx, Ly, and Lz are the three dimensions of the room; l, m, and n are mode numbers; and c0=344 [m/s] is the speed of sound in air in normal conditions of temperature and air pressure.

Room modes (standing waves) arise when sound reflections between room boundaries reinforce each other at specific frequencies, producing resonance (eigenfrequencies). At these frequencies, the room does not behave like a uniform container of sound: instead, fixed regions of high sound pressure (antinodes) and low sound pressure (nodes) form, so measured SPL depends strongly on microphone and listener position. This effect is most pronounced at low frequencies, where only a few modes dominate and the modal spacing is wide, causing large spatial variations across a room. In rectangular rooms, modal families are commonly described as axial (involving one dimension), tangential (involving two dimensions), and oblique (involving three dimensions).

In 2011 research, Oliva et al. Claim that when the sound enters the room, the room modes are the strongest at low frequencies. Absorption of room boundaries is negligible at low frequencies, and as a consequence, even relatively modest levels of low-frequency noise outside a building may lead to significantly higher levels at particular positions inside a room. For architectural acoustics, this means that room geometry, boundary conditions (parallel surfaces), and absorption/furnishings can unintentionally amplify or suppress low-frequency components, which has direct implications for both measurement strategy and perceived indoor annoyance (Oliva et al., 2011).

6.4. Spectrogram-based complaint cases

Pedersen et al (2017) provide a detailed spectrogram-based view of how these sources behave in real dwellings by equipping occupants with a low-frequency recording device and analysing three complaint cases: a restaurant cooling compressor, a residential heat pump, and nearby wind turbines.

6.4.1. Cooling compressor case

The occupant lives next to a restaurant where cooling compressors vent through an outlet mounted on the wall near the occupant’s window, and they made over 20 recordings across different times (day/evening/night) and locations (rooms, hallway, and outside by the restaurant). The worst-case spectrogram (Figure 7) shows speech at the start, followed by impulse sounds (footsteps and a closing door), and then a clear dominant tonal component around ~47–48 Hz that fluctuates in frequency and level.

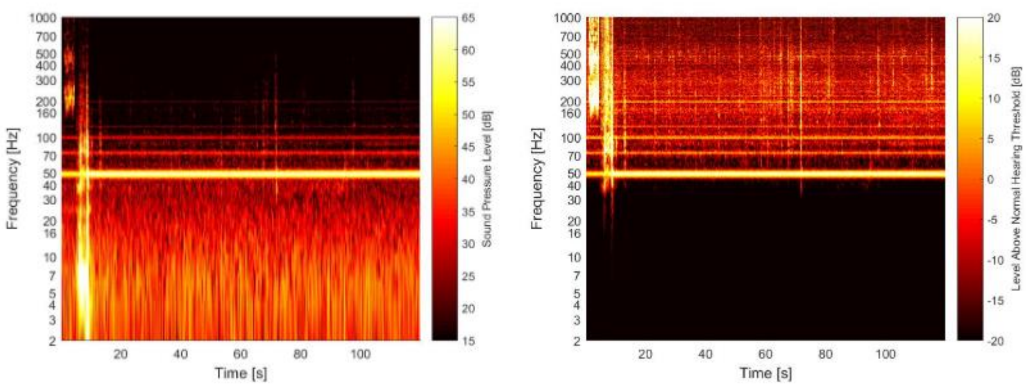

Figure 7. Left: spectrogram (logarithmic frequency axis) of a recording in a room in the apartment. Right: Same recording with a spectrogram where the level is weighted according to the normal hearing threshold (ISO389-7:2005) (Pedesen et al., 2017).

The 48 Hz tone becomes stronger after the door is closed, for which the authors argue that it is likely because the closed door changes reflections and the standing-wave pattern in the room. A threshold-weighted spectrogram (right) indicates that content below the tone is inaudible, while higher frequencies are audible but less prominent than the ~47–48 Hz component. In the left spectrogram, it is evident that the whole spectrum below the hearing threshold line exists at significant SPL levels (up to around 45 dB). The same spectrogram, as is observable, indicates a pulsating rhythm over the temporal dimension.

The spectrograms below (Figure 8) present recordings outside of the apartment. The left one is showing the recording in the hallway outside of the apartment, and the right one is showing a recording outside of the back door of the neighbouring restaurant.

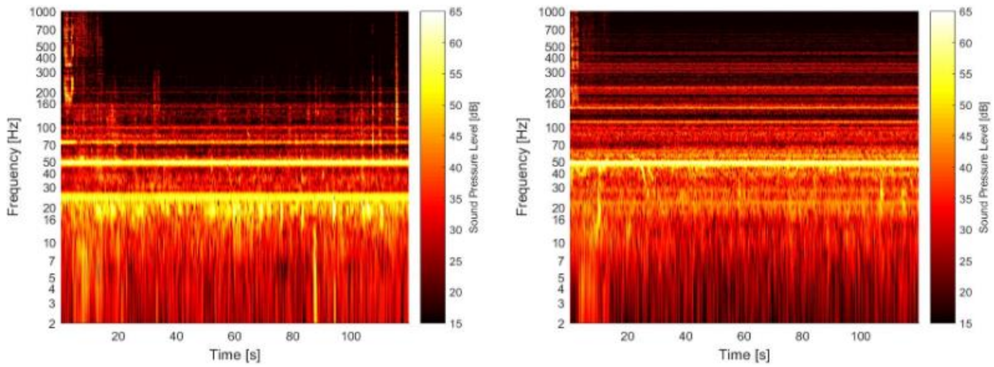

Figure 8. Left: Spectrogram of a recording in the hallway outside the apartment. Right: Spectrogram of a recording outside of the backdoor of the neighbouring restaurant (Pedersen et al., 2017).

It is observable that in both spectrograms the line of the frequency at around ~23 Hz is showing, but on the left one (the hallway outside of the apartment) it is significantly more prominent.

6.4.2. Heat pump case

In this case, a neighbouring heat pump is located close to the occupant's house, and the occupant made several recordings both indoors and outdoors (at the facade and at the property boundary). It is noted that because the noise is non-stationary, it was difficult to capture consistently. The indoor recordings did not show audible low-frequency noise; instead, they revealed some mid-frequency tones, confirming that the system can also detect mid-frequency components. When the occupant was presented with these results, it became clear that the main issue was outdoors, supported by multiple outdoor recordings showing a fundamental around 48 Hz that corresponds to the harmonic structure seen in the indoor data (Pedersen et al., 2017).

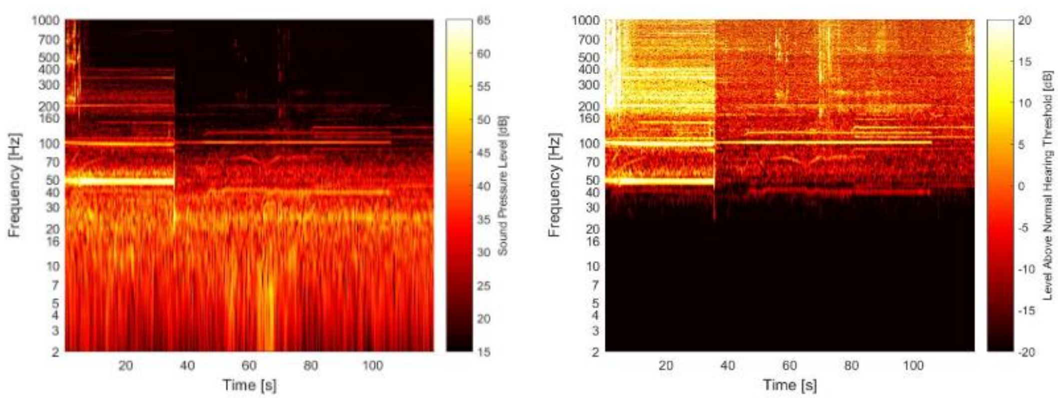

Figure 9. left: Spectrogram of an outdoor recording. Right: a threshold-weighted spectrogram of the same recording (Pedersen et al., 2017).

Again, the left, non-threshold-weighted, spectrogram is showing significant SPL levels of infrasound, which appear not to have a stable SPL through time, meaning that it may be a fast-pulsating sound, which would align with the way of operating of these machines. There is, again, a faint, almost consistent with higher SPL, at around 23 Hz.

6.4.3. Wind turbine noise case

In this case, the occupant suspected nearby wind turbines as the source of low-frequency noise and therefore made recordings at different times and positions, including indoors, outdoors, and closer to the turbines. An indoor living-room recording shows a dominant tonal component around 68 Hz with higher harmonics that vary in level.

An outdoor recording taken about an hour later, roughly 190 m from the nearest turbine, contains the same tonal components, strengthening the source attribution. The time variation is consistent with wind turbine noise, since wind direction, wind speed profile, and turbulence change over time, and the findings are also in line with the official turbine measurement report, which reports a pronounced 68 Hz tone, especially at higher wind speeds.

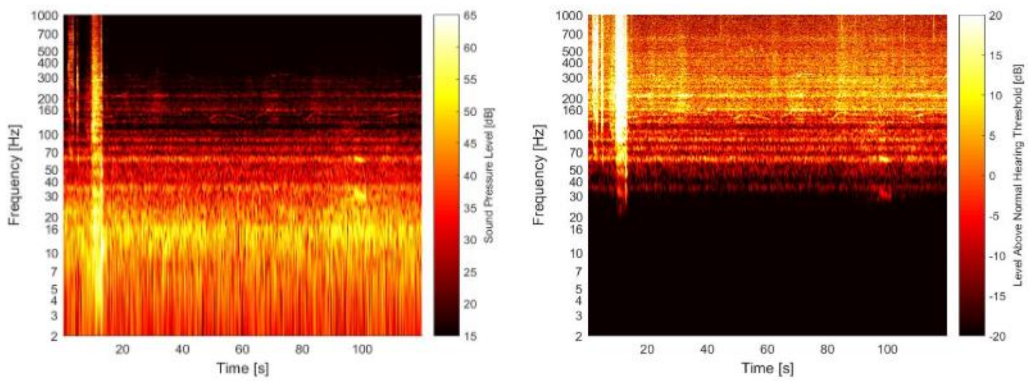

Figure 10. Left: Spectrogram of a recording in the living room. Right: a threshold-weighted spectrogram of the same recording, (Pedersen et al., 2017).

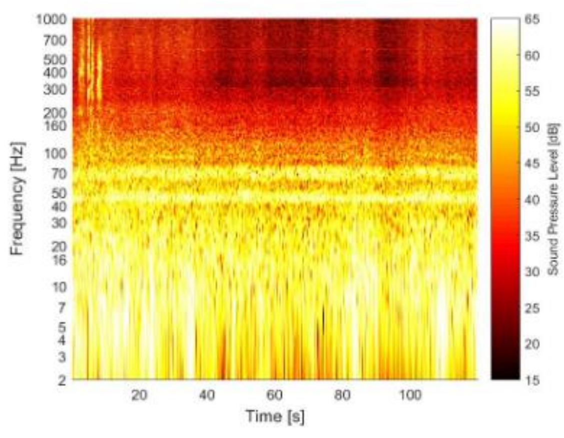

Figure 11. Spectrogram of an outdoor measurement 190 m from the nearest wind turbine (Pedersen et al., 2017).

The spectrogram in Figure 8 shows infrasound levels with an SPL value at around 35 dB, peaking at around 50 dB, especially around 8-17 Hz. Outside recording marks significantly high SPL level (around 55 dB), but the inside recording does not seem to peak at the same frequency, nor does the inside level peak at lower frequencies, which are up to 65 dB of SPL.

7. Furniture as a possible mitigator

Oliva et al (2006) modelled a simple rectangular room (6 × 4 × 2.5 m, ≈60 m³) to study how absorption panels and furniture influence the low-frequency sound field. In the reference case, the room was empty, and all boundaries were treated as perfectly reflecting (case 6a). A second case added three mineral-wool panels on the walls, and a third introduced typical furniture, with all items acoustically hard except for a porous wool sofa (case 6b). In the third case (6c), the room was excited by a small planar broadband source, chosen to minimise transmission-path effects and isolate how added absorption and furnishings reshape the indoor sound distribution. Below in Figure 12, cases 6a and 6c are depicted.

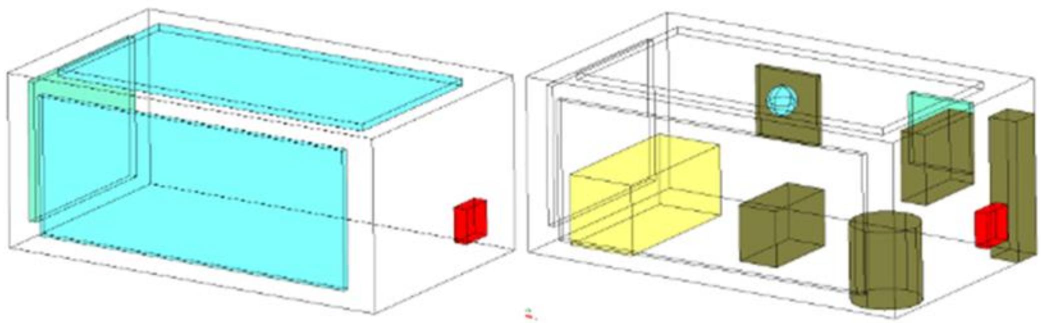

Figure 12. left: Case 6b (blue = absorbing panels; red = planar source). Right: Case 6c (green = furniture; yellow = sofa; panels not coloured) (Oliva et al., 2006).

In those models, two frequencies were played: a 50 Hz band and a 160 Hz band. At 50 Hz, the SPL distribution at 1.5 m height is presented for the empty room, Case 6A, and the furnished/absorptive room, Case 6C, in Figure 20. In the empty-room case, the spatial pattern is dominated by a clear modal structure. The authors identify a mode lmn = 010 around 49 Hz, and show that this modal behaviour is strongly disturbed once absorption and furniture are introduced.

The practical consequence is exactly what one would expect when a resonance is “broken”: the maximum SPL decreases in Case 6C, primarily because overall absorption is higher and the resonance behaviour is less coherent. At the same time, the minimum SPL stays approximately the same.

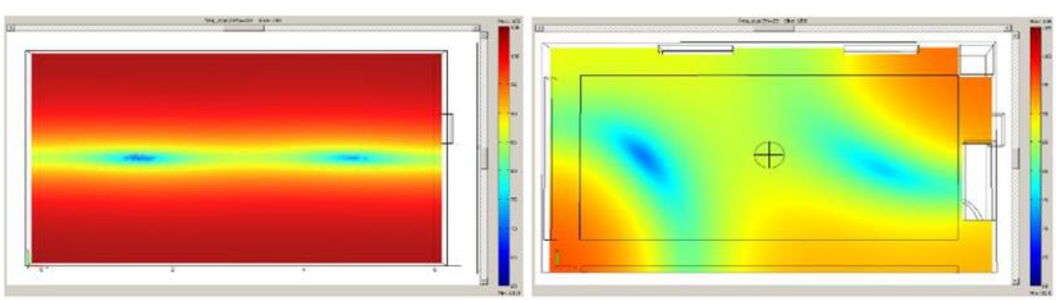

Figure 13. SPL at 1/3 octave 50 Hz. Left) Case 6A. Right) Case 6C. Both figures are at a height of 1.5 m. SPL scale is between 60 (blue) and 105 dB (red) (Oliva et al, 2006).

Using the modal relation, a 6 × 4 × 2.5 m room has first axial modes at approximately 28.6 Hz (length), 42.9 Hz (width), and 68.6 Hz (height). This places the 50 Hz band close to low-order modal behaviour, which is consistent with the strong spatial pattern observed in the empty-room case. This is evident from the figure 21 were undisturbed ~50 Hz component is near resonant, and may still experience noticeable reinforcement, due to proximity to the ideal theoretical modal resonant frequency. In this 6a case, the SPL peaks near the opposite walls at ~105 dB, and in the middle of the axis, it is ~75 dB.

In the case of 6c, it is evident that the furniture and fittings dampened the SPL levels to the range of ~75-85.

Although Oliva et al (2006) examined modes at 50 Hz rather than in the infrasonic band, their findings illustrate a general principle: adding furniture and limited porous absorption to an otherwise empty rectangular room reduced the strength and spatial contrast of low-frequency standing waves. By disturbing the coherence of the dominant mode, maximum sound pressure levels dropped by roughly 20–30 dB at some positions, while minima remained similar, making the room's response less "peaky". Given that room modes at slightly lower frequencies follow the same wave physics, this suggests that even ordinary furnishings can act as mild mitigators of low-frequency build-up, although dedicated low-frequency treatments would be required to affect true infrasound more substantially.

8. Discussion

The reviewed evidence demonstrates that infrasound is neither a purely paranormal curiosity nor a speculative military phenomenon, but a measurable acoustic factor that can interact with architectural space and human physiology. However, several limitations must be acknowledged before drawing architectural implications.

First, much of the empirical data originates from laboratory exposures or isolated case studies, where conditions differ substantially from everyday residential environments. Laboratory experiments often employ controlled intensities and frequencies, whereas domestic exposure is typically low-level, continuous, and embedded within complex noise spectra. This discrepancy cautions against direct transfer of laboratory findings to architectural practice without further validation.

Second, individual sensitivity to infrasound varies considerably. While ocular resonance at ~19 Hz or vestibular sensitivity at ~7 Hz has been documented, not all individuals exposed to these frequencies report perceptual anomalies. Psychological expectations, environmental co-factors, and personal susceptibility may modulate responses. This variability highlights the need for cautious interpretation and for design strategies that prioritize minimizing exposure rather than assuming uniform effects.

Third, contradictions among studies remain unresolved. Some research links infrasound to anxiety, stress markers, or cognitive modulation, while others report negligible or inconsistent outcomes. These discrepancies may reflect differences in measurement protocols, exposure levels, or analytical methods. Importantly, many residential complaints involve spectral content extending into the infrasonic range, yet conventional A-weighted measurements underrepresent or exclude these frequencies. This methodological blind spot contributes to interpretive fragmentation across acoustics, physiology, and architecture. The Coventry cellar is an example of where an environment could have influenced the perception of the space and the feelings of 'being haunted' that arose, which might have already been appearing from visual cues, rather than infrasound alone, which might have only been an amplifier. It is extremely important to take the whole environment into account while analysing such cases.

However, the documented effects of infrasound shall not be ignored or categorised as an overblown ghost story. With modern advances in technological appliances and infrastructure, the issue of infrasound is becoming more prevalent. It has been proven that infrasound does affect the body in various ways: subtly reshaping brain activity and connectivity, elevating stress hormones, increasing irritability and negative appraisal, and elevating salivary cortisol, even when it is not consciously heard (Ascone et al., 2021, Forlim et al., 2024; Kasprzak, 2012, 2014; Scatterty et al., 2026; Stepanov et al., 2003; Weichenberger et al., 2015, 2017).

From an architectural perspective, the most relevant insight is that built space itself can act as a resonant system. Room modes, standing waves, and boundary conditions may amplify low-frequency components generated by household appliances or building services, producing localized "hot spots" of pressure and vibration. Such amplification does not require extreme intensities; even modest outputs from compressors or fans can become perceptually significant when reinforced by geometry. This recognition reframes infrasound as a spatial variable, instead of it being merely a technological by-product.

The cooling compressor case (Pedersen et al., 2017), the spectrogram shows clear amplification of the ~48 Hz frequency when the doors were closed, as the authors have claimed, assuming it happened due to reflections in the enclosed space. The outside of the backdoor of the neighboring restaurant recording showed the same dominant frequency (~48 Hz) and faint lines in the lower spectrum, including the ~23 Hz frequency. That implies that the ~23 Hz frequency was not dominant, but rather a part of the spectrum. What is interesting is that in the hallway outside of the apartment, as shown in Figure 6, the frequency is amplified up to ~55 dB.

The information about the dimensions of these apartments, or the hallway, is not presented, but if the geometry of the hallway is amplifying—resonating with—that specific frequency, it would be calculated with the already presented formula: $f = c/2L$, where L is the distance between two walls, c is the speed of sound, and f is the frequency.

If the speed of sound were taken as 334 m/s, at the temperature of 20 °C, the distance between two walls would, for the perfect resonance, have to be ~7,5 m. That length occurring is plausible, but unfortunately, the exact floor plans are not available, so this calculation is a speculation, not a fact. Furthermore, using the same formula, for amplification by resonance of the ~48 Hz frequency, one dimension of the room in which the sound was measured would need to be ~3,6 m, which is also a plausible occurrence.

The wind turbine case (Pedersen et al., 2017) shows, in the spectrogram recorded 190 m, away from the turbine (figure 7), a vast spectrum of soundwaves below 60 Hz, at high intensities, but the inside-of-the-apartment recorded spectrogram (figure 8, left) does not seem to have that same frequency spectrum as excited, but rather the ones between 10-16 Hz seem to be more prominent. Knowing that lower-frequency sound waves travel long distances and around obstacles without losing energy quickly, it is safe to assume that they have all arrived at the apartment with a similar SPL. That may imply natural enclosed space resonance amplifying, however, without available dimensions of the living room, it is impossible to conclude if the reason for the excitement of these specific frequencies is the room geometry.

The possible room dimensions remain speculations due to the lack of data; however, the spectrograms shed light on a broader problem—standard A-weighted measurements ignore a significant portion of inaudible soundwaves, which may affect humans through the body, avoiding the

Although the frequency analysed is clearly not infrasound and is audible, research by Oliva et al (2006) provides valuable insight into how low-frequency sound waves could be mitigated by furniture positioning.

Despite this still being an under-researched field, it is of utmost importance to continue research in this direction, since architecture itself should never be divided from the comfort of its users, and if it makes even a slight difference in the quality of their lives, it needs to be explored.

9. Sick Building Syndrome

Constant exposure to low-frequency and infrasonic components has been described as a background stressor, which must be coped with continuously and can therefore contribute to chronic stress symptoms when individuals cannot "switch off" the demand to cope (Benton & Leventhall, 1994; Leventhall et al., 2003; Gregorio et al., 2001). Frequency noise centred around ~7 Hz was identified in several investigated office rooms, and many occupants in those spaces reported symptoms commonly grouped under "sick building syndrome" (e.g., fatigue, headaches, nausea, dizziness, and concentration difficulties). Frequency noise centred around ~7 Hz was identified in several investigated office rooms, and many occupants in those spaces reported symptoms commonly grouped under "sick building syndrome" (e.g., fatigue, headaches, nausea, dizziness, and concentration difficulties).

10. Salutogenic Approach—Design Workflow

From a salutogenic architectural perspective, integrating infrasound awareness into the design workflow can be understood not as the creation of a separate specialist discipline, but as a structured extension of existing design and evaluation procedures aimed at supporting healthier and less stressful living environments. At the earliest concept and planning stage, potentially relevant low-frequency sources—such as compressors, heat pumps, split air-conditioning units, lift machinery, chillers and large ventilation fans—should be identified and, where possible, located at a distance from bedrooms, living rooms and other restorative dwelling spaces, with consideration of both airborne and structure-borne transmission paths. During spatial and structural design, the expected spectral content of such sources should be assessed using full-spectrum or Z-weighted data rather than A-weighted indices alone, so that low-frequency and infrasonic components are not excluded at the outset. On that basis, basic room-acoustic calculations, including room-mode and resonance analysis, can be applied to spaces most likely to be occupied for long durations, while simple three-dimensional modelling may help visualise potential low-frequency pressure maxima or spatial "hot spots." The resulting acoustic knowledge can then be fed back into the project through adjustments in room proportions, service placement, enclosure design, and the positioning of sensitive functions away from predicted zones of amplification. Finally, where complaints arise after occupation, post-occupancy evaluation should include measurements extending below 20 Hz alongside conventional audible-band assessment, so that infrasonic components and room-gain effects can be identified rather than remaining invisible within standard practice.

11. Conclusion

This review has demonstrated that infrasound, though inaudible to most occupants, represents a measurable environmental factor with potential implications for health, comfort, and perception in built spaces. Evidence from acoustics, physiology, and environmental psychology confirms that low frequency fields generated by everyday building services can interact with architectural geometry, producing localized resonance zones that overlap with human resonance ranges. While findings remain heterogeneous and individual sensitivity varies, the architectural significance lies in recognizing buildings as resonant systems that can unintentionally sustain infrasonic fields.

Measurements in occupied dwellings show that everyday sources such as HVAC systems, refrigerators, ventilation fans and distant wind turbines can, under specific spatial and structural conditions, generate localised "hot spots" where room modes amplify particular frequencies by tens of decibels. In these situations, architecture functions not as a neutral backdrop but as an active acoustic filter and amplifier, shaping how residents experience low-frequency sound. The point is not that household appliances are malicious or equivalent to acoustic weapons, but that overlooked interactions between mechanical systems and enclosure geometry can reproduce some of the perceptual patterns described in laboratory research.

These findings suggest that infrasound in buildings should be understood less as an isolated hazard and more as an amplifier within a broader sensory and psychological ecology. Achieving healthy rather than "sick" buildings therefore requires integrating low-frequency acoustics into design and diagnostic practice alongside light, thermal comfort and air quality. At the same time, the existence of therapeutic uses of low-frequency sound reinforces a broader ethical point: the same physical phenomena can support healing or harm, depending on context, control and exposure. Future work should combine detailed room-acoustic modelling, in-situ measurements and longitudinal occupant feedback to establish practical low-frequency design guidelines and to clarify when architectural interventions can meaningfully improve residents' quality of life.

By reframing infrasound as a spatial and environmental variable, this study contributes to salutogenic and evidence-based architecture. Practical implications include service placement and isolation, careful room proportioning, and the integration of low-frequency monitoring into post-occupancy evaluations. Limitations of current measurement practices, particularly reliance on A-weighted indices, highlight the need for more comprehensive standards below 20 Hz.

11.1. Further Investigations

This paper calls for further investigations to move beyond isolated case reports and controlled laboratory studies towards integrated, real-world assessments of infrasound in dwellings from an interdisciplinary perspective. Future work should ideally combine long-term low-frequency measurements in occupied homes with detailed information on room geometry, source characteristics and occupant experiences, including sleep quality, mood and stress markers. Experimental studies could systematically vary both frequency and temporal modulation of low-frequency fields at realistic levels, to clarify which patterns of exposure are most relevant for background stress and annoyance. Finally, closer collaboration between architects, acousticians, structural and mechanical engineers, psychologists and health researchers is needed to test how design decisions—such as room proportions, placement of compressor-based systems and furnishing strategies—alter the low-frequency sound field and whether targeted architectural interventions can measurably improve occupant well-being.

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Conflicts of Interest
The authors declare no conflict of interest.

Data Availability Statement
The study is based on previously published literature and case studies; no new experimental or survey data were collected. All sources used are cited in the reference list, and no additional datasets were generated or analysed.

Institutional Review Board Statement
This research did not involve new experiments on humans or animals, nor the collection of personal data, and, therefore, did not require approval by an institutional review board or ethics committee.

Contribution to the Field Statement
This paper argues that infrasound should be integrated into architectural thinking, rather than limiting acoustical relevance to A-weighted sound levels that privilege only the audible spectrum. It synthesizes

evidence from acoustics, physiology, and environmental psychology to show that household appliances and building services, both independently and in interaction with architectural geometry, generate a full spectrum of low-frequency sound waves, including components below the threshold of hearing. The paper analyses how these sources interact with architectural space and, coupled, affect dwellers. It explicitly calls for further research and encourages architects to embed infrasonic awareness into design workflows, standards, and post-occupancy evaluation.

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