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Evaluating Noise Pollution and Health Impacts from Cooling and Ventilation Systems in Inner City, Copenhagen

Interactive Qualifying Project Report

Copenhagen D26 Project Center

Worcester Polytechnic Institute

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Evaluating Noise Pollution and Health Impacts from Cooling and Ventilation Systems in Inner City, Copenhagen

An Interactive Qualifying Project
Submitted to the faculty of
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in partial fulfillment of the requirements for the
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Report Submitted to:

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Abstract

This project evaluates whether current Danish noise regulations adequately account for low-frequency noise (LFN) produced by cooling and ventilation systems in Copenhagen. LFN exposure poses adverse health risks, including sleep disturbance, stress, depression, anxiety, and reduced well-being. Through surveys, interviews, and field measurements, discrepancies between measured noise and perceived annoyance were identified, revealing that current practices do not fully account for LFN. The results highlight the need for improved regulations to better address LFN to enhance the quality of life in the community.

Executive Summary

Noise is an unavoidable consequence of urbanization, arising from sources such as traffic, construction, industrial, recreational, and neighborhood sounds. As cities grow and technology progresses, noise levels have been increasing, resulting in many unwelcome outcomes. While definitions vary, noise pollution is typically considered an unwanted human-produced sound that negatively affects human or animal well-being. Noise pollution has many unforeseen health impacts, such as increased cortisol, depression, anxiety, cardiovascular stress, heart problems, and decreased quality of sleep. Therefore, addressing noise pollution is crucial for the betterment of any community.

Current Danish noise standards primarily focus on quantifying sound levels using A-weighted decibel measurements, which fail to adequately capture low-frequency noise (LFN) that is commonly generated by cooling and ventilation systems. This results in many LFN sources continuing to operate at levels people find uncomfortable, despite meeting current regulations. Therefore, the goal of this project was to support Miljøpunkt Indre By Christianshavn, a nonprofit that focuses on environmental work in the Inner City and Christianshavn, in evaluating whether current Danish noise measurement standards adequately account for low-frequency environmental noise in Copenhagen's Inner City district. Specifically, this project focused on low-frequency noise (LFN) generated by cooling and ventilation systems and its health effects and annoyance to residents. To achieve this goal, the project followed three primary objectives:

1. Assess local Copenhagen residents', municipality and committee members', and noise experts' opinions on current levels of noise from cooling and ventilation systems, especially in residential and commercial areas.

2. Measure and analyze cooling and ventilation systems to evaluate differences between measured levels and perceived public annoyance identified in Objective 1.

3. Present findings to workgroups and the Inner City committee on discrepancies between measured noise pollution and perceived annoyance by Inner City residents, along with developing a webpage with our findings on the sponsor's website.

Objective 1 involved surveying Inner City residents and interviewing residents, technical noise experts, and a member of the municipality in the Sound and Outserving department. The survey revealed that residents favor stricter noise regulations and identified music, restaurants, traffic, and construction as the primary noise sources, while cooling and ventilation noise was mentioned only once. Additionally, three technical professionals with different areas of expertise in noise were interviewed for their perspectives. This included an employee of Force Technology's noise, acoustics, and vibrations department, a member of the Municipality of Copenhagen in the Sound and Outserving department, and a lead audio engineer who works in research and design at Jabra. These interviews suggested a disconnect between public knowledge and existing legislation. Especially, how the public's limited knowledge in identifying and reporting low-frequency noise, the technical challenges of measuring LFN, and inadequate legislation contribute to continued community dissatisfaction.

Objective 2 entailed gathering A- and C-weighting measurements of cooling and ventilation systems and comparing them to perceived annoyance and regulatory standards. C-weighting better captures LFN, while A-weighting reflects what humans can hear. Data was collected using the sponsor-provided Hand-Held Analyzer Type 2250 from Brüel & Kjær to measure noise levels of indoor spaces adjacent to two cooling and ventilation systems in the Inner City. To select measurement points, proper Danish measurement procedures were identified during the technical interviews in Objective 1, specifically, the Danish Environmental Protection Agency Guidance No. 9/1997. As current standards are focused on A-weighted levels, which fail to account for LFN, official measurements of cooling and ventilation noise often fall below the regulated limits resulting in no further action from either the municipality or the party responsible for the noise to reduce it. This is exemplified by the measurements for the second objective, as the A-weighted levels usually meet regulations, and therefore, nothing legally needs to be changed. Additionally, the A-weighted levels experience less difference in recorded decibels while the cooling and ventilation system is on or off. However, the C-weighted noise measurements show a notable difference when the system is on or off, as C-weighting best captures LFN. Therefore, these measurements, albeit anecdotal, support the need for more comprehensive legislation surrounding low-frequency noise.

Objective 3 combined the findings from Objectives 1 and 2 to compile a presentation for the Inner City Local Committee and workgroups. The presentation was created by using aggregated survey results, interview notes, sample noise measurements, and background research, and was presented on April 15th, 2026. The content was well received, and the committee members were very interested in the issue and project results. In particular, they asked multiple questions about next steps, as well as recommendations for future projects and goals to reduce low-frequency noise. They were also very interested in identifying action items the public and municipality can take to limit LFN. Several members attended the final Interactive Qualifying Projects presentation on April 30th, 2026.

Based on these findings, it was recommended that the Municipality of Copenhagen consider collecting C-weighted measurements while addressing noise complaints to accumulate data to support possible legislative changes to noise regulations. Regulations on LFN and the inclusion of C-weighted measurements for these scenarios should be backed by the public, unions, work-groups, and the municipality to advocate for parliamentary changes. Additionally, mitigation strategies, such as reducing power to noise sources, adding dampeners, or using noise barriers, should be applied to cooling and ventilation systems whenever possible, especially larger systems or those closer to residential areas. It is also recommended that Miljøpunkt Indre By & Christianshavn use their platform and connections within the Inner City to inform the public about the health issues that stem from noise pollution, the gaps in regulations for measuring LFN, and how best to identify and report LFN complaints. This can be accomplished through public events, Miljøpunkt's newsletter and website, and general emails to union leaders.

It is relevant to address the problem of noise pollution in all of its facets, but particularly low-frequency noise from cooling and ventilation systems. It is important to start with public awareness of the health impacts of LFN and how to best identify and describe LFN. Then, al-

tering the municipality's measuring methods to gather C-weighted measurements could support regulatory changes with citizen support.

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First and foremost, we would like to express our sincere gratitude to Marianne Spang Bech for providing resources and information. Without her valuable knowledge and connections, this project would not be possible. We gratefully acknowledge the support of Miljøpunkt Indre By & Christianshavn for providing the resources and comforting work environment necessary for this research. We would like to acknowledge the interviewees for their willingness to share their perspectives and knowledge, which provided invaluable depth to this project. Special thanks to all the residents who took the time to complete our survey and share their valuable input on the unique noise-related experiences they face. Additionally, we extend our appreciation to our advisors, Professor Francesca Bernardi and Jeffrey Solomon, for their invaluable guidance and support throughout the project. We are also thankful to Professor Seth Tuler for his insightful feedback and understanding in establishing the foundation for our work. Finally, we would like to thank our fellow student, Jonah Muccigrosso, whose initial research into the health effects of noise proved vital to the project. Without the shared contributions of these individuals, this project would not have been possible, and we extend our profound gratitude for their support.

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1 Introduction

Copenhagen is widely recognized as one of the world's most sustainable, safe, and livable cities. Danes value renewable energy, climate adaptation, and maintaining a high quality of life for residents (European Environment Agency, 2021b). However, as cities continue to modernize and grow, an increasing number of people are exposed to disruptive levels of noise pollution, leading to more people being affected by its negative effects (Tan et al., 2022). In the greater Copenhagen area, home to over 1.4 million people, over 60% of the population experiences high noise levels (>55dB) during the day, and more than 40% at night (>50dB) (European Environment Agency, 2021a). Excessive noise is often overlooked but can have negative mental and physical health impacts regardless of its type. However, noise pollution is an understudied topic, with research typically focusing on the noise created by transportation services (cars, planes, trains) and industrial/construction activities (Arenas, 2026).

The Municipality of Copenhagen has implemented several strategies to reduce noise pollution. By establishing different noise limits in different city zones and times, they have partially limited excessive noise in specific areas and during daytime hours. As such, quieter residential regions tend to have stricter regulations, especially at night. For example, the typical limit values measured at neighboring boundaries are 45-55 dB(A) during the day, 40-45 dB(A) during the evening, and 35-40 dB(A) during the night (Municipality of Copenhagen, 2025). Sounds such as rain or a running refrigerator fall within these noise limits.

For more than 10 years, the Danish environmental organization Miljøpunkt Indre By & Christianshavn has had three key areas of focus: a healthy city, a green city, and a circular city, each with its own specific aims to improve the local area. One of their current missions is to reduce noise from sources such as heating, ventilation, and air conditioning (HVAC) systems and nightlife, to improve community standards by targeting areas with high noise levels.

The goal of this project is to support Miljøpunkt Indre By & Christianshavn in evaluating whether current Danish noise measurement standards adequately account for problematic low-frequency environmental noise in the Inner City district of Copenhagen. This goal was accomplished through three objectives:

1. Assess local Copenhagen residents', municipality and committee members', and noise experts' opinions on current levels of noise from cooling and ventilation systems, especially in residential and commercial areas.

2. Measure and analyze cooling and ventilation systems to evaluate differences between measured levels and perceived public annoyance identified in Objective 1.

3. Present findings to workgroups and the Inner City committee on discrepancies between measured noise pollution and perceived annoyance by Inner City residents, along with developing a webpage with our findings on the sponsor's website.

These accomplishments will help Miljøpunkt Indre By & Christianshavn's goal of raising awareness of the harmful effects of noise pollution generated from cooling and ventilation systems. In turn, this will hopefully spark efforts on the local level to persuade a change in legislation and regulations.

2 Background

Noise is an unavoidable consequence of urbanization, arising from sources such as traffic, construction, recreational activities, and neighborhood sounds (Tan et al., 2022). With the growth of cities and rapid technological progress, noise levels have been increasing in both urban and rural environments (Rosing et al., 2025). While definitions vary, noise pollution is typically considered an unwanted human-produced sound that negatively affects human or animal well-being (Arenas, 2026).

The World Health Organization (WHO) recognized noise as a pollutant in 1972 (de Paiva Vianna et al., 2015). Subsequently, in 2002, the European Union enacted Directive 2002/49/CE to manage and mitigate noise pollution. This directive established a systematic approach to measuring noise, set limit values on the amount of noise produced, raised public awareness, and implemented legislation (The European Parliament And The Council Of The European Union, 2002). In 2017, more than one million individuals in Denmark's urban areas were exposed to noise levels exceeding EU reporting standards (European Environment Agency, 2021b). Understanding the relationship between urban environments and noise exposure is crucial for improving public health, promoting urban sustainability, and improving the noise landscape (Chen et al., 2024).

This chapter examines the characteristics that contribute to noise pollution in urban environments, which is typically influenced by transportation, neighborhood, aircraft, industrial, and construction noise. However, low-frequency noise (LFN) generated by cooling and ventilation systems is frequently underexamined. Lower-frequency noise is often underrepresented in current measurement standards despite its commonality in residential and urban settings. The health impacts of such noise pollution can be extremely detrimental, as it may increase cortisol levels, directly correlating to lack of sleep, depression, and potential psychological effects (Babisch, 2011). Therefore, addressing gaps in noise measurement with policymakers and relevant regulatory bodies is critical, as it may support the development of legislation to improve public health, citizens' quality of life, and overall community well-being.

2.1 Urban Noise Sources

Individuals encounter numerous sources of noise in daily life, which may affect overall health and well-being. These sounds range from relatively subtle, routine background noise to louder, more disruptive, and often erratic sounds. Understanding the origins of noise pollution is essential for developing effective mitigation strategies, as responses vary by scenario. Major sources of urban noise include transportation, neighborhood, construction, recreational, and industrial noise.

2.1.1 Transportation Noise

Transportation noise is the primary source of noise pollution in large cities and is considered the most disturbing source (de Paiva Vianna et al., 2015). It includes noise produced by cars, trucks, motorcycles, and other road traffic (González et al., 2024). Engines, exhaust systems, and tire-road interactions all generate transportation noise, which is exacerbated through higher

speeds and traffic volumes (González et al., 2024).

2.1.2 Neighborhood Noise

Neighborhood noise comes from households, including generators, air conditioners, pets, home music systems, and appliances. Noise from these sources is often irregular due to variations in duration and volume. Therefore, regulating these erratic sources within residential homes is difficult. Additionally, people spend much of their time in the presence of household noise, which significantly affects sleep quality and well-being (Babisch, 2011).

2.1.3 Other Noise Sources

Other common sources of noise include construction, recreational activities, industrial operations, aircraft, and airport operations. Large cities often see new building projects, which result in added construction noise. Heavy equipment, such as excavators, jackhammers, and cranes, produces intense noise. Construction is frequently done during the early morning and afternoon hours, adding to the problem of disturbing residents in their homes (Arenas, 2026).

Industrial facilities include manufacturing plants, power generation facilities, and mining operations. The noise class and intensity generated vary by industry type. Recreational activities include events and leisure pursuits outside of the home, such as restaurants, bars, gyms, and stadiums. Many of these feature amplified sound systems that are used late into the night. The combination of a large gathering, music, and an exciting atmosphere results in a hot spot of noise (Arenas, 2026).

Aircraft and airports generate intense noise in concentrated areas and are usually regulated with zoning and spatial planning laws. However, aircraft noise is typically considered less important than other sources due to the sounds being concentrated in isolated areas along with existing regulations (Arenas, 2026). Although fewer people are exposed to aircraft noise than traffic noise, people find aircraft noise more annoying and more severely disturbs sleep than traffic noise at the same level (González et al., 2024).

2.2 Measuring Noise Pollution

The characterizations of sounds and regulations to control noise are grounded in two variables: frequency and magnitude. Frequency relates to a sound's pitch, with higher frequencies corresponding to higher pitches. Magnitude relates to the intensity of a sound and is commonly measured in decibels (dB). Both affect how people experience sound and why sounds can be experienced as noise, specifically how low-frequency noise can be underestimated despite its significant health effects. The following sections explain the difference between high and low frequency, and how various measurement methods quantify the magnitude of noise differently.

2.2.1 High & Low Frequency

A signal's frequency is categorized as either high or low, and although "noise" is often associated with high-pitched sound, some of the more psychologically disruptive noise comes

from the lower end of frequencies. Low-frequency noise (LFN) is classified as anything below 250 Hz, and high-frequency noise (HFN) is anything above 250 Hz. The high-pitched chirping of a bird is an example of high-frequency noise, while the sound of a tuba has a significantly lower pitch, qualifying as LFN. This idea is further exemplified in Figure 1, which depicts the difference between high- and low-frequency sound waves.

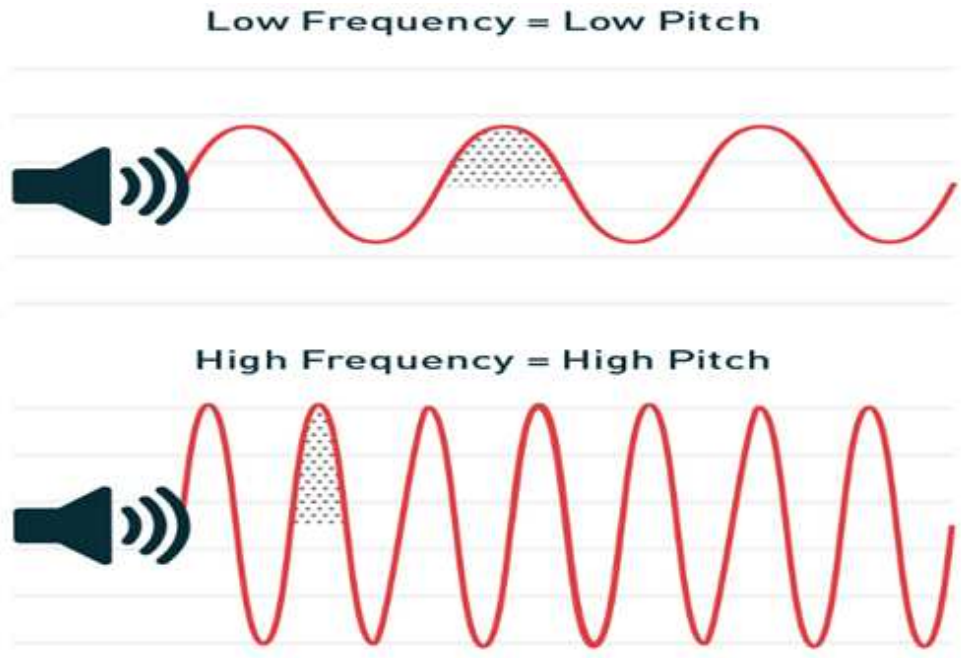

Figure 1: Visual representation of low- and high-frequency waves (How Acoustic Foam Effects Sound Waves: Holland | SoundFix, n.d.).

There are substantial differences in how low- and high-frequency noise propagate and the impacts they produce (Thakre & Vijay, 2024). LFN can be felt more than heard, because the human ear cannot hear lower frequencies. Additionally, LFN can travel greater distances and transmit more easily through materials (Thakre & Vijay, 2024). Issues have arisen in noise regulations standards due to measuring within the human hearing sensitivity, thereby underestimating LFN. Common sources of LFN in urban settings include cooling and ventilation systems, heavy machinery, traffic, and industrial equipment (Thakre & Vijay, 2024).

2.2.2 Decibels (dB)

Decibels (dB) are the unit of measurement for noise, meaning the louder the noise, the higher the decibel count (Government of Quebec, 2022), as described in Figure 2. However, because humans can only hear within a specific frequency range, sound measurements are often adjusted using frequency weighting or certain measuring methods. A-weighted noise measurement (dB(A)) focuses on sound levels heard by humans and excludes other sound frequencies. There is also the C-weighted noise measurement (dB(C)), which measures lower frequency ranges. It tends to be better at measuring loud, bass-heavy, or industrial sounds, including cooling and ventilation noise, machinery, and engines. For example, when measuring noise produced by a sound woofer, an A-weighted measurement would read 75 to 80 decibels, while a

C-weighted measurement would read 90 decibels because it has a less filtered frequency range (Vernier, 2018).

Noise levels above 75 dB(A) can have severe effects on hearing. However, even at lower decibels for prolonged periods, the human body can be adversely affected. For example, during sleep or while focusing, the body can be disturbed by noises as low as 40 dB(A), which is around the sound level of a whisper (Government of Quebec, 2022). Cooling and ventilation systems typically operate at 50-60 dB, which is equivalent to a quiet conversation, and older machines can be as loud as 100 dB (Trane, 2026). Sound level meters are used to measure noise.

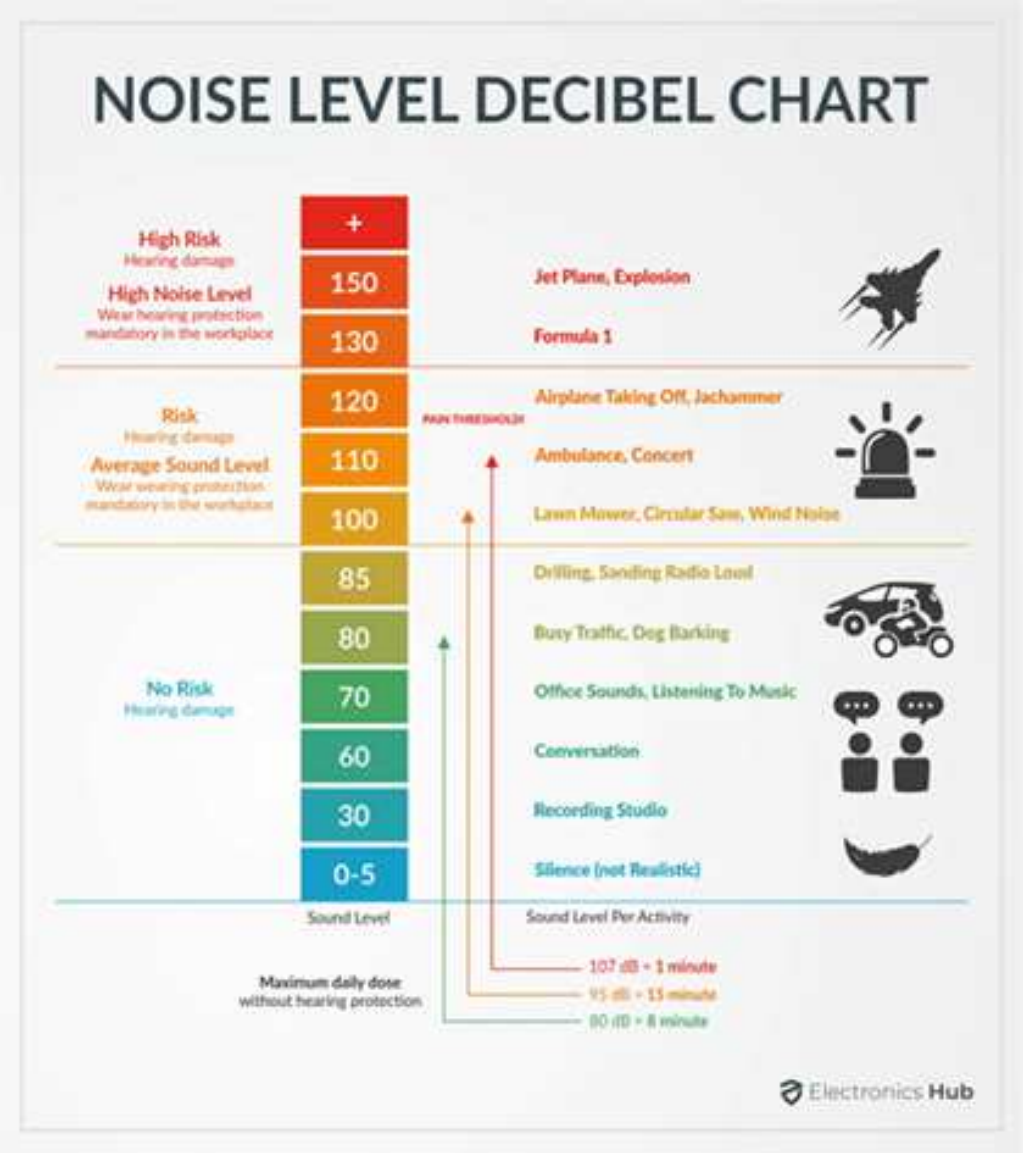

Figure 2: Noise level decibel chart (Data Smart, n.d.).

2.3 Health & Wealth Impacts of Noise Pollution

Noise is often categorized as a nuisance rather than a problematic issue with real-world health effects (World Health Organization Regional Office for Europe, 2018). Research has shown

numerous negative health effects from prolonged exposure to certain sounds and frequencies (Babisch, 2011). This problem is especially prevalent in Europe, with a growing number of cooling, heating, and temperature-control systems producing low-frequency noise (European Environment Agency, 2025). While biological mechanisms of noise-induced stress, such as heart strain and possible hormonal imbalance, are universal, the degree of exposure is often a reflection of socioeconomic disparity (Dreger et al., 2019). As such, when considering the health impacts of noise pollution on an individual's social landscape, personal wealth, housing, and urban density must be accounted for.

2.3.1 Health Problems Derived from Noise Pollution

Prolonged noise exposure, particularly LFN, triggers chronic stress in the human body. Unlike other sounds, LFN is often perceived as a vibration, which puts the body into a state of constant environmental stress. This thereby engages the body's nervous system, leading to increased cortisol levels, i.e., the stress hormone (Babisch, 2011). Ultimately affecting sleep quality, leading to a multitude of other problems. Continuous low-quality sleep and a constantly engaged nervous system result in prolonged stress on the cardiovascular system. When under consistent stress, it becomes more difficult to enter a deep sleep. As a result, there is a buildup of inflammation and oxidative stress within the vascular endothelium, increasing the risk of hypertension and heart disease, as seen in Figure 3, and heart failure (Münzel et al., 2020).

Another negative health effect from noise pollution is increased rates of depression, anxiety, irritability, and cognitive impairment (Ganatra, 2024). The brain interprets constant noise as a sign of instability and subconsciously depletes emotional energy (Ganatra, 2024). This is particularly clear with LFN from cooling and ventilation systems, revealing a link between noise and higher rates of depression and anxiety (Pulakka et al., 2025). In addition, LFN can affect children's cognitive abilities. When children learn in a high-noise environment, they can experience 'cognitive masking,' where background noise can severely hinder reading and language skills (Clark & Paunovic, 2018).

2.3.2 Health, Wealth, and Noise Pollution

The health impacts of noise pollution are not equally distributed across socioeconomic lines. This creates a significant gap in how noise pollution affects people from various backgrounds. Wealth often acts as a barrier to noise pollution, as individuals with greater means can afford solutions to ward off noise. Some examples include quieter, more costly cooling and ventilation systems, quieter living spaces, and better noise-proofing materials within the home. Affluence often enables living in neighborhoods with stricter zoning laws (Casey et al., 2017). In contrast, low-income households are often situated near high-traffic areas, airports, or industrial complexes, which have vast amounts of machinery and cooling and ventilation equipment. Since people in these areas may not be able to afford quieter cooling solutions, they often get stuck in areas with elevated noise pollution, where many negative health effects can be realized (Casey et al., 2017).

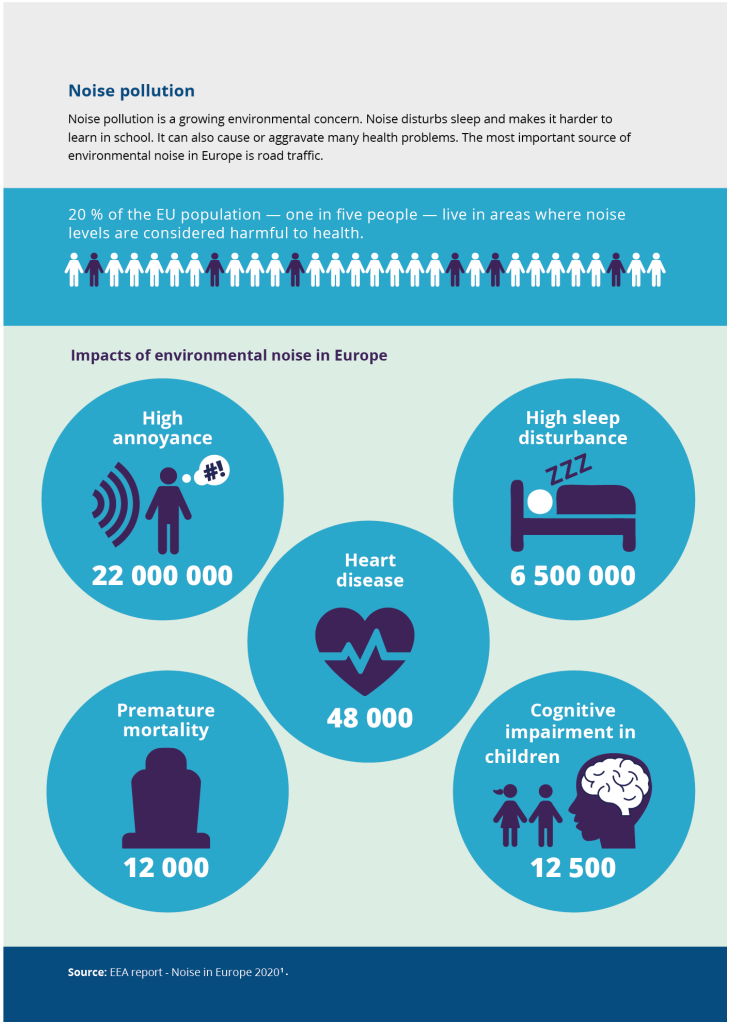

Figure 3: European Environmental Agency Report on noise in Europe (European Environment Agency, 2025b).

2.3.3 Noise Impact on Economics

While wealth can act as a shield against noise pollution, the broader economic consequences of noise pollution can drain the local economy. For instance, the economic value of property can be significantly affected by noise pollution. Research into hedonic pricing, or how outside factors influence property value, shows that areas with extensive noise create 'noise ghettos' where value is very low due to noise pollution (Moretti & Wheeler, 2025). In addition, Copenhagen reports that property value can increase up to 1% (0.5% for apartments) for each decibel of noise that is reduced (The Danish Environmental Protection Agency, n.d.). This ties back to the idea that people with less money cannot afford to live in areas with lower noise pollution, leading to increased side effects for these individuals. Also, the societal cost of these 'noise ghettos' extends to a measurable effect on workplace productivity and increased healthcare costs (Moretti & Wheeler, 2025). Noise pollution is more than annoying sounds, as it can have a seriously negative impact on urban communities and disproportionately affect low-income households.

2.3.4 Denmark's Upcoming National Health Law

The National Health Law is a cornerstone of the Government's Health Reform 2024 agreement, which introduces Denmark's first public health legislation. This act aims to strengthen public health through national law, tackling both the technical aspects of health and its underlying societal issues. As previously noted, health outcomes vary along socioeconomic lines, and this act seeks to ensure equitable access to a healthy and dignified life. Furthermore, given the growing strain on the welfare system and the prospect of labor shortages, enabling older citizens to lead longer, active lives independent of support is crucial. Simultaneously, adults and young people need to thrive mentally and physically within supportive environments. This new legislation will ensure that the state, regions, and municipalities follow the same guidelines and objectives that are based on preventive and health-promoting efforts. The National Health Law, set to take effect on January 1, 2027, is designed to be completed over the following eight to ten years, with ongoing updates every four years to set a common strategic direction for the comprehensive development of health services.

2.4 The Unique Issue of Noise Pollution from Cooling and Ventilation Systems

Cooling and ventilation systems are understudied and yet provide constant sources of noise pollution in urban areas (Ouis et al., 2025). Unlike previously discussed sources, such as transportation or construction, cooling and ventilation systems operate continuously to control household temperatures and air quality. This constant background noise becomes especially noticeable and detrimental during quiet periods, such as nighttime, often proving to be more disruptive and stress-inducing than intermittent noise sources (Ouis et al., 2025). Additionally, research has shown that cooling and ventilation systems produce low-frequency noise, which is less masked by other noise sources and harder to tolerate, even at low levels (Ouis et al., 2025).

In urban cities, such as Copenhagen, where mixed-use buildings, apartment complexes, and public spaces are often densely packed, rooftop and wall cooling and ventilation units, along with ventilation ducts and equipment/control rooms, are situated directly next to or connected to residential living spaces. The proximity of living spaces to cooling and ventilation systems increases the likelihood of noise and vibrations propagating through buildings, disturbing residents (Ouis et al., 2025). As a result, cooling and ventilation systems represent a frequently overlooked but important source of noise pollution in urban areas, and as such, require technical and policy-driven attention.

2.4.1 Sources & Characteristics of Cooling and Ventilation Noise

The noise created by cooling and ventilation systems primarily originates from mechanical and aerodynamic processes that systems undergo throughout usage. The most common sources of noise come from fans, compressors, ducts, and various mechanical components that comprise the systems. While rotating components (fans, compressors, etc.) create noise via vibrations caused by component imbalances, defects, and blades interacting with air, the turbulent airflow

within cooling and ventilation ducts is also a major contributor to the produced noise pollution. As turbulent airflow moves through the bends and restrictions of the ducts, it generates aerodynamic shear and pressure fluctuations, which in turn produce "broadband acoustic emissions" that escape through the duct vents, as seen in Figure 4 (Ouis et al., 2025).

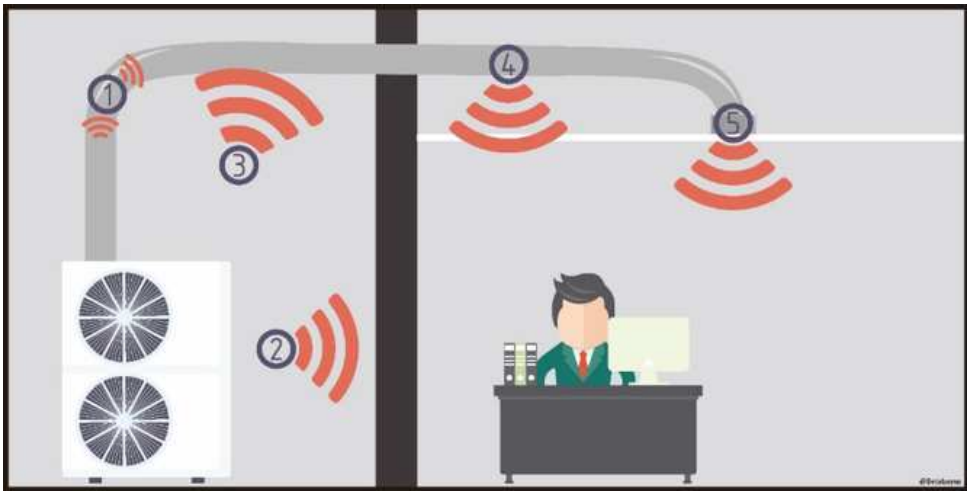

Figure 4: The acoustic layout of a cooling and ventilation system (Geonoise Instruments).

2.4.2 Sound Transmission & Urban Exposure

Once generated, noise from cooling and ventilation systems can be transmitted to surrounding areas via vibrations. This noise propagates through structures integrated with or close to the systems. This vibrational energy can be transferred throughout the building's structures, spreading noise to areas far from the cooling and ventilation unit (Ouis et al., 2025). These transmissions are particularly significant in urban areas, as many buildings share walls and have cooling and ventilation equipment close to where people work and live. Furthermore, sound waves diffract around and over walls and structures, spreading as they travel and reducing the effectiveness of simple noise barriers (Manuel, 2005). As a result, noise produced on rooftops or walls by cooling and ventilation systems can extend far beyond the source, affecting multiple neighboring residences, creating a community-wide issue.

A case study examining the impact of cooling and ventilation systems on residential zones found that insulation plays a significant role in reducing noise pollution as lower frequencies tend to maintain a higher sound intensity indoors (Thakre & Vijay, 2024). The study also backs up the earlier idea that homes experience low-frequency exposure, especially at night, which in turn contributes to poor sleep quality (Thakre & Vijay, 2024). The article mainly focuses on the glazing ratio of doors and windows and how strongly it affects noise pollution. For instance, larger window areas increase exposure to external noise, but double-glazed windows help reduce noise. Although the article does not go into detail on specific measurements, it mentions the mass law, explaining that the heavier the object, the less it vibrates. In Copenhagen, it is important to consider how lower-income areas experience higher levels of noise pollution due to the lower quality of materials used in residential buildings (Thakre & Vijay, 2024).

As discussed, noise pollution transmission pathways are heavily influenced by building layouts and urban planning and the effectiveness of controlling cooling and ventilation noise, and noise pollution in general, depends not just on the design of the cooling and ventilation equipment, but also on the façade layout, spacing between buildings, and the distance cooling and ventilation systems are from living and working areas (York, 1972). In *Controlling Urban Noise Through Zoning Performance Standards*, York emphasizes that community noise pollution must be addressed through policy and planning-based solutions rather than solely through technical system-level improvements. He argues that "Scientific controls and enforcement standards have developed which can be integrated with a municipality's zoning code to regulate a major portion of community noise" (York, 1972). Consequently, limiting noise pollution from cooling and ventilation systems in large cities, such as Copenhagen, requires not only building-level solutions but coordinated policies and planning strategies on the community-wide level.

2.5 Mitigation & Control Strategies

Solutions for controlling and mitigating noise pollution from common sources such as traffic, construction sites, residential areas, and airports (Arenas, 2026) can serve as a reference when considering how to reduce noise from cooling and ventilation systems. Various methods have been implemented in urban areas to reduce noise pollution, with the optimal approach varying by source. As such, determining the ideal processes to combat disruptive noise is vitally important. Figure 5 represents one such path to effectively eliminating noise.

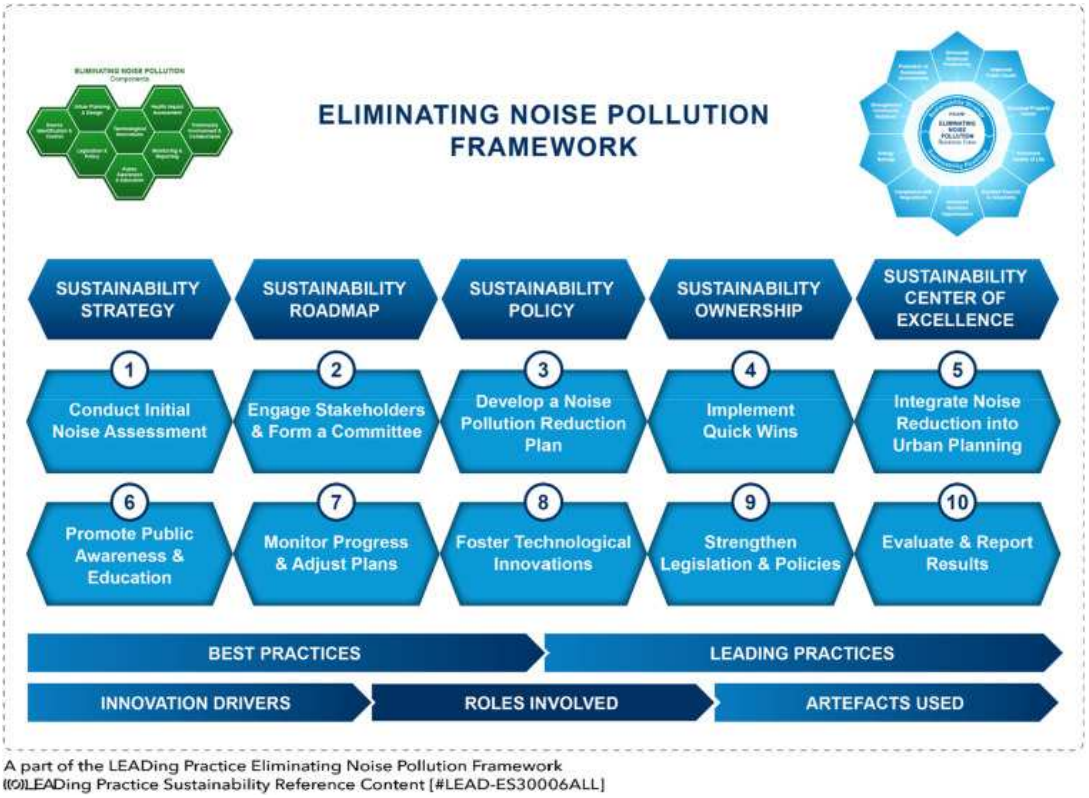

Figure 5: Framework for eliminating noise pollution (Rosing et al., 2025).

To effectively manage the various sources of noise pollution listed in Sections 2.1 and 2.2, cities have implemented regulations, encouraged the adoption of quieter technologies, promoted improved urban planning and zoning, and educated the public about its impacts (Rosing et al., 2025). Furthermore, technological advancements are key to reducing noise; the creation of quieter engines, machinery, and industrial equipment has been instrumental in lowering noise levels. Innovations in building materials that offer enhanced sound insulation, along with noise-cancelling technology, are also significant. As such, continued research and development are essential for ongoing progress in noise reduction.

Proper urban planning and zoning also play a large role in keeping noise levels down. Deliberately adding green spaces, buffer zones, noise barriers, and separating noise-sensitive areas from noise-generating areas are simple urban design changes for mitigation. Under the Act on Spatial Planning, areas where sound levels exceed recommended thresholds, such as roads, railways, and industrial plants, cannot be planned for noise-sensitive building uses like housing or buildings with overnight accommodation unless mitigation measures are incorporated in the development plan (Ministry of Environment and Gender Equality, n.d.-b). Additionally, when authorities grant an environmental permit to a plant, recommended noise limits must be followed, as well as a description of the noise level that will occur (Ministry of Environment and Gender Equality, n.d.-b).

2.6 Current Regulations & Policies

Along with the strategies discussed in Section 2.5, regulations and legislation can be important to the management of noise. Local governments can enact noise regulations and enforce them with penalties. Additionally, incentives can be implemented to increase community compliance. Legislation creates clear standards and guidelines surrounding noise levels for specific times of day and in noise-sensitive zones. These regulations help to increase public awareness and community engagement, which are vital in reducing noise pollution. Public awareness and community support for noise reduction efforts come naturally as people become more informed about the associated health risks, sources, and practices to promote a quieter environment (Rosing et al., 2025).

Noise pollution in Copenhagen is governed by several layers of regulations that operate at the European, national, and municipal levels. These regulating parties address noise both as an environmental and public health concern, but because regulations are distributed across different governing bodies and policies, noise regulation can be difficult for residents to interpret without a clear understanding of how the system is organized and what kinds of noise are regulated at each level.

2.6.1 Layers of Noise Governance

Combining international public health guidelines, European regulatory frameworks, national policy, and municipal enforcement, noise regulation in Copenhagen is shaped by a system of influence to help cover all bases and keep occupants healthy. These layers function hierarchically,

using scientific evidence and guidelines to inform policy at national and local levels.

At the highest level of influence, the World Health Organization provides the public health foundation for environmental noise regulation across Europe. The WHO's (World Health Organization Regional Office for Europe, 2018) compile scientific evidence on the relationship between environmental noise exposure and negative health effects, helping to set limits to avoid the public enduring those health impacts. The guidelines recommend health-based exposure levels for multiple noise sources and are intended to support decision-making by European countries (World Health Organization Regional Office for Europe, 2018). These guidelines are not legally binding, but they serve as an accredited reference for understanding the health implications of noise and establishing the public need for noise regulation.

Building on this scientific foundation from the WHO, the European Union provides a legal framework, such as the Environmental Noise Directive. This Directive does not directly adopt the WHO-recommended exposure limits or provide uniform thresholds across the European countries; it requires standardized assessment, mapping, action planning, and public information on environmental noise (The European Parliament And The Council Of The European Union, 2002). By establishing consistent reporting structures, the European Union can ensure that noise exposure is systematically identified while leaving specific values and mitigation measures to national and local authorities, allowing for more stringent policies where necessary.

At a national level, Denmark codifies European Union requirements into a technical system through the Danish Environmental Protection Agency (EPA). The EPA is responsible for coordinating and publishing noise maps, as seen in Figure 6, as well as reporting to the European Union; the initial noise mapping of Copenhagen was completed in 2007, and a second phase with more detail and a wider area in 2012 (Ministry of Environment and Gender Equality, n.d.-b). These maps use data reporting on noise levels from traffic in major urban environments in the country, exposing areas that need sound barriers and showing what areas may be receiving the most noise exposure. National public health authorities further reinforce the framework by communicating the health implications of noise exposure using evidence from the WHO recommendations. Additionally, the Danish Social and Housing Agency regulates construction processes and products to ensure the safety and health of building occupants through the enforcement of the Building Act (Danish Social and Housing Agency, n.d.).

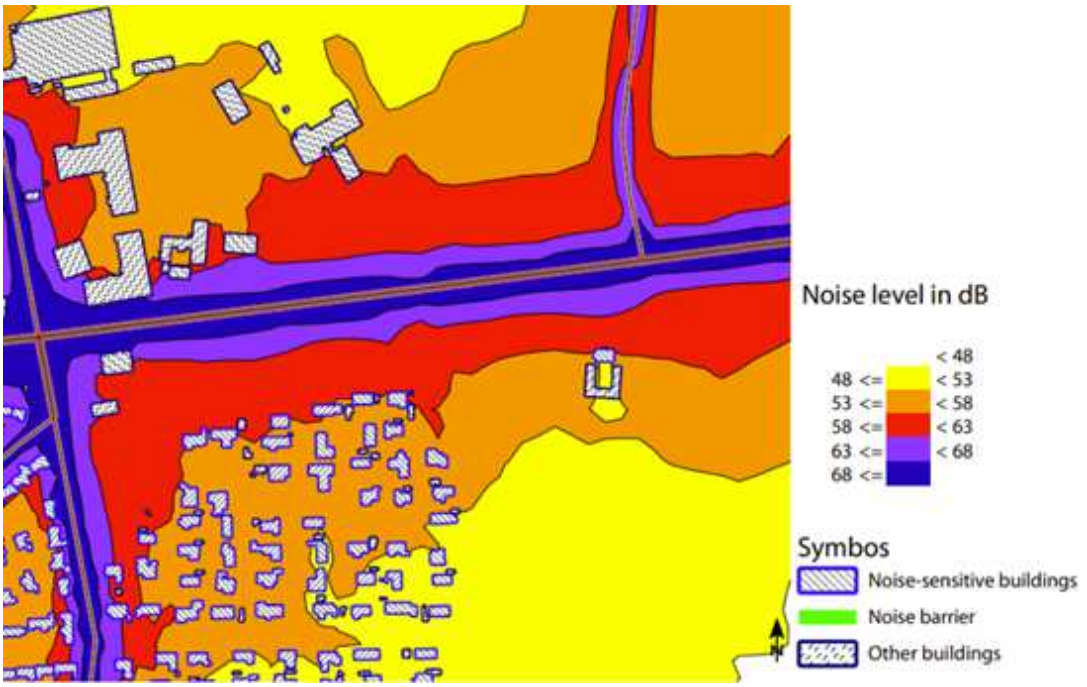

Figure 6: Example of a noise map provided by Denmark's EPA (Lene Nøhr Michelsen og Jakob Fryd and Road Directorate Allan Jensen and A/S, R. D., 2010).

At the municipal level, Copenhagen applies national frameworks to local conditions through enforceable bylaws and legislation. Municipal agencies such as the Climate, Environmental, and Technical Administration help oversee the regulation of these policies and work with residents to maintain public health as it relates to noise regulation (Klima-, Miljø- og Teknikforvaltningen | Københavns Kommune, n.d.). Copenhagen's adoption of targeted regulations addressing noise from cooling and ventilation systems is informed by the WHO recommendations, but can be more nuanced to best cater to the city's needs.

In addition to municipal oversight, the Inner City has district-level governance to focus on local priorities. Each of the 12 districts in Copenhagen has its own Local Committee, with the Inner City Local Committee, established in 2008, being made up of 23 members and managing approximately DKK 2.6 million in funds for the district (Formål og opgaver | Indre By Lokaludvalg, n.d.). Monthly meetings are open to the public, and the Local Committee acts as a liaison between the Copenhagen City Council and the residents of the Inner City (Formål og opgaver | Indre By Lokaludvalg, n.d.). Through these public forums, residents can influence decisions as it relates to their living environment, including noise-related concerns.

2.6.2 Cooling and Ventilation Noise Regulations in Copenhagen

General noise policies address environmental noise exposure broadly, but cooling and ventilation systems present a more localized and technical regulatory challenge. The continuous low-frequency noise produced may not be immediately apparent during building design or installation, leading to variances in performance based on installation. To combat this and improve consistency, the Danish Social and Housing Agency's BR18 gives regulations for ventilation specifically in *Chapter 22: Ventilation* (Danish Social and Housing Agency, n.d.). At the

municipal level, the Copenhagen City Council adopted a bylaw in 2025 focused on reducing the noise levels from cooling and ventilation systems, specifically targeting regulation on heat pumps. This legislation reflects a movement toward source-specific regulation, targeting large building systems that contribute to persistent urban noise (Municipality of Copenhagen, 2025). While independent from national building codes, the bylaw ties together building regulation, system placement, and operation to meet this new criterion.

The adoption of Copenhagen's revised regulation on noise from cooling and ventilation systems followed a formal municipal legislative process, including public consultation, administrative review, and political deliberation (Municipality of Copenhagen, 2025). During the consultation phase, local committees and citizens were able to submit their input and comments on the proposed legislation. This process influences how the regulation is interpreted and refined. The administrative review process identifies where clarification is needed based on this feedback, illustrating how public input can shape the community's regulations. While the legislation came from the Technical and Environmental Administration, the people of Copenhagen are the ones who decide what they want for their community. After gaining the approval of the City Council, the updated requirements for cooling and ventilation systems were formally implemented.

2.7 Significance of Noise Pollution for Inner City Residents

The legislative framework in the Inner City is set to serve the people who inhabit the district, and more can be done to address environmental noise exposure in the dense urban area. Mixed-use areas where residential buildings are situated near commercial properties and mechanical systems are particularly susceptible to continuous noise that can disrupt quality of life and occupant health. Even when systems follow technical requirements, residents may still experience disruption, highlighting the disconnect that exists between regulatory standards and the lived experience.

Addressing noise pollution in the Inner City, as shown in Figure 7 is not only a regulatory issue, but one that requires greater awareness among legislative and policy decision-makers. Many policymakers may underestimate the extent to which noise exposure contributes to health effects and daily disruptions experienced by residents. Increasing awareness among legislative members about the sources, impacts, and prevalence of environmental noise is a critical step toward developing effective regulations and mitigation strategies. Understanding how residents perceive environmental noise and documenting its impacts can provide valuable evidence to inform policy decisions and support healthier living conditions in the Inner City.

Figure 7: Map of the Inner City district in Copenhagen, Denmark.

3 Methodology

The goal of this project was to support Miljøpunkt Indre By & Christianshavn in evaluating whether current Danish noise measurement standards adequately account for problematic low-frequency noise (LFN) in the Inner City of Copenhagen. The project gathered perspectives from a member of the Municipality of Copenhagen, noise experts, and the community to understand how noise affects people. The municipality provided professional standards, an overview of the complaint process, and how complaints changed over time. While noise experts advised on measurement methods, opinions on current regulations, and the difficulties of measuring and legislating LFN. The public provided firsthand experience of the noise within the Inner City and how it impacts life. The approach connected public, private, and municipal input and presented the information to workgroups and the Inner City committee. Additionally, relevant resources were added to the Miljøpunkt Indre By & Christianshavn website to inform the public.

To achieve the project goal, the following objectives were tackled:

1. Assess local Copenhagen residents', municipality and committee members', and noise experts' opinions on current levels of noise from cooling and ventilation systems, especially in residential and commercial areas.

2. Measure and analyze noise from cooling and ventilation systems to evaluate differences between measured levels and perceived public annoyance identified in Objective 1.

3. Present findings to workgroups and the Inner City committee on discrepancies between measured noise pollution and perceived annoyance by Inner City residents, along with developing a webpage with our findings on the sponsor's website.

By completing these objectives, we supported Miljøpunkt Indre By & Christianshavn in informing the public about the impacts of noise pollution and advocating for improved legislation. Increasing awareness of these issues should foster civil engagement to mitigate them, either through government pressure or personal actions. For instance, residents may be more likely to work with their local committees and advocate for applicable change when well educated.

3.1 Assess Residents', Local Officials', and Experts' Opinions

Objective 1 involved gathering opinions from Inner City residents, municipality officials, and noise experts. Individuals from all three groups were interviewed, and residents were surveyed as well. The survey gauged a general sense of public opinion of noise, while the interviews delved deeper into the technical aspects and personal problems. The survey began with an introduction to the project and its goals, explaining the importance and usefulness of their participation. This was followed by a request for informed consent, which was needed to continue. The consent prompt also informed respondents of their right to skip questions and assured them of complete confidentiality. Contact details for the sponsor and the IQP group were provided for any inquiries or concerns.

Surveys for residents covered four principal areas: current opinions on noise levels, identifying noticeable noise sources, understanding of noise regulations and standards, and whether

subjects filed an official complaint about noise. These questions were developed to accommodate a wide range of residents, acknowledging their different experiences with noise, complaints, and regulatory knowledge. Some questions were open-ended, while others used a scale from 1 to 5 or 1 to 10. The scale allows for easy comparison of results, while questions with free-response answers gave subjects the flexibility to answer as they saw fit. Participants had the option to provide contact information for potential follow-up interviews or to request a specific source of noise to be measured. One resident was interviewed after the survey to gain a deeper understanding of their perception of noise, especially regarding low-frequency noise from ventilation and refrigeration systems. The survey was offered in Danish and English (Appendices A1 and A2), and distributed via email to workgroups and unions, included in the sponsor's monthly newsletter, and promoted with flyers featuring QR codes, as shown in Figure 8 below.

Figure 8: Flyers designed to promote the survey for Inner City residents in English [LEFT] and Danish [RIGHT].

Interviews were conducted online or at the interviewee's preferred location. Each interview included at least two research group members and was recorded after obtaining the interviewee's informed consent. Five interviews are expected: one with the municipality, one with Force Technology, an audio engineer at Jabra, and two with Inner City residents (Appendices B, C, D, and E).

3.2 Measuring Noise and Comparing to Residents' Opinions

Noise from two cooling and ventilation systems in the Inner City was measured using the sponsor-provided Hand-Held Analyzer Type 2250 Light and Type 2250 from Brüel & Kjær, as shown in Figure 9. These measurements were then compared with the perceived public

annoyance with noise as found in Objective 1, along with data from the municipality. Data from the municipality included previous noise measurements in the Inner City, measuring methods, and complaint frequency.

Figure 9: Hand-Held Analyzer Type 2250 Light [LEFT] and Type 2250 [RIGHT] from Brüel & Kjær.

To learn how to use the Hand-Held Analyzers to measure noise, we read the user manuals, watched tutorials, and discussed measuring techniques with local noise experts. Preliminary measurements followed the Danish standard and used A-weighted frequency measurements to account for LFN. Then, a broad frequency setting capable of measuring both A- (HFN) and C-weighted (LFN) frequencies was used to measure the same source. The recorded data from both methods were then compared to determine the difference between A-weighted and C-weighted measurements. The first location was selected due to its proximity to the office space, where people have complained about low-frequency noise. The second location site was determined through one survey respondent. The first site followed the Danish EPA Guidance No. 9/1997, which meant getting a control measurement with the system off and another measurement with the system on. The second site did not follow the guidance due to time constraints, the inability to turn off the low-frequency noise source, and respect for the survey respondent. Only one measurement point was taken instead of three, and were measured for a shorter time. Despite these limitations, the main ideas of the difference between A- and C-weighting are still shown.

Nevertheless, to follow the guidance as best possible, two measurements were taken: one in the room with the highest LFN annoyance and one in a room farther away where it was less of a problem.

Measurement points were selected following the Danish Environmental Protection Agency Guidance No. 9/1997 "Low-frequency noise, infrasound and vibrations in the external environment" and demonstrated in Figure 10. The guidelines state that all measurement points must be at least 0.5 meters from the walls, floor, and ceiling, and each point has different distances from the walls, floor, and ceiling. Measurement points should be at least 2 meters apart, if possible. No measurement points should be near the center of the room due to the risk of registering an atypically low sound pressure level, leading to inaccurate results. The recommended measurement points should be at least 20 centimeters from the centerline that divides the room equally in height, length, and width. All measurement points were recorded, along with their respective distances from the walls, floor, and ceiling.

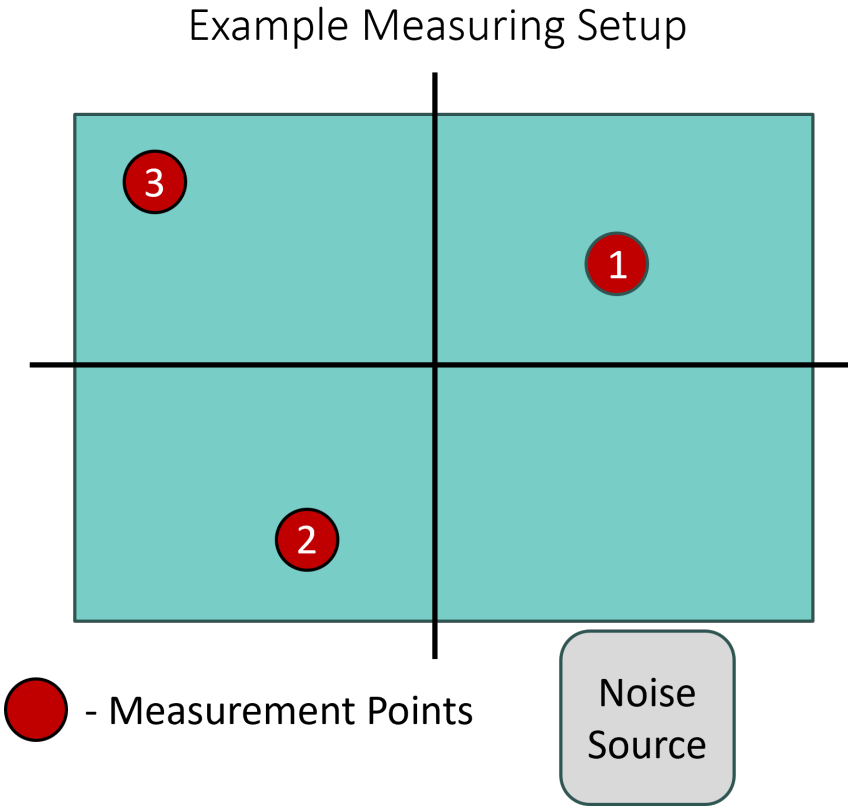

Figure 10: Example of measurement point set up following Danish EPA Guidance no. 9/1997.

3.3 Presentation for the Inner City Local Committee and Work-groups and Adding to the Sponsor's Website

The findings from Objectives 1 and 2 were used to create a presentation for the Inner City committee and local environmental work groups. The presentation included aggregated survey results, interview notes, sample noise measurements, and background research. The

focus of the presentation was to identify and illustrate discrepancies between the Danish broad-frequency standards for measuring noise and the perceived public annoyance to inform the local committee and workgroups of this issue. The survey results were used to highlight human interactions and perceptions of noise, such as how much noise annoys them daily, and sources they find most bothersome. The technical interviews revealed many of the current problems with LFN measurements in the legislative framework. The measurements from Objective 2 were used to provide sample data of the difference between A- and C-weighting to help illustrate the importance of using the appropriate weighting type for the source. This was all used to support the idea of revising current standards and regulations to encompass LFN.

In addition to the presentation, our findings are publicly accessible on the sponsor's website. The webpage started with the abstract to supply readers with a synopsis of the entire project. The project's proposal from Miljøpunkt Indre By & Christianshavn was also added to the page to offer more context. Additionally, the final report was attached to provide readers with easy access to the entire project. Two slideshows were also added: the presentation given to the Local Committee partway through the project and the final presentation report. This webpage serves to update survey participants on the project's progress and informs the public about the health effects of noise pollution. The aim is to raise awareness not only of the annoyance caused by LFN but also of its long-term consequences.

4 Results

This project sought to help Miljøpunkt Indre By & Christianshavn determine whether current noise standards are sufficient for addressing problematic low-frequency noise (LFN) in the Inner City. To begin, Inner City residents were surveyed and interviewed to gauge public opinion on existing noise levels, identify significant noise sources, and determine whether current regulations should be more stringent. In addition, several technical professionals were interviewed about their perspectives. Then, a couple of cooling and ventilation systems were measured to compare noise levels with perceived annoyance. Finally, the findings were compiled into a presentation for the Local Committee and workgroups, aimed at informing their members and encouraging policy change, along with adding information to the sponsor's website.

4.1 Results for Objective 1 – Assess Local Copenhagen Residents', Municipality & Local Committee Members, and Noise Experts' Opinions

Objective 1 assessed residents' relationship with noise and how professionals work with noise. This assessment was completed by creating a survey for residents about their noise experiences (Appendices A1 and A2) and interviewing two technical professionals, a member of the Municipality of Copenhagen, and two residents of the Inner City (Appendices B, C, D, and E).

4.1.1 Survey Results

The survey was designed to assess the public's perception of noise and its standards. It covered perceived noise annoyance, irritating sources of noise, opinions on regulations, and whether respondents would be interested in a follow-up interview.

Eighteen responses were received, with participants' average age approximately 59 years, ranging from 30 to 85 years. Noise is a common disturbance that affects daily life, as shown in Figure 11. Frequently mentioned sources of noise included traffic, music from cafes and restaurants, noise from people, and construction work. Low-frequency noise sources, such as cooling and ventilation systems, were only mentioned by one participant. Despite a diverse familiarity with current noise standards, as shown in Figure 12, most of the participants agreed that the current regulations should be stricter, as depicted in Figure 13. Survey respondents reported having complained to a wide selection of people, including the municipality, noise patrol, police, the cafes/restaurants responsible for the noise, and the housing association. Formal complaints to the municipality or police have seen minimal success in addressing the reported issues. This information, in conjunction with the interviews, gave a deeper understanding of the problems of noise pollution in the Inner City.

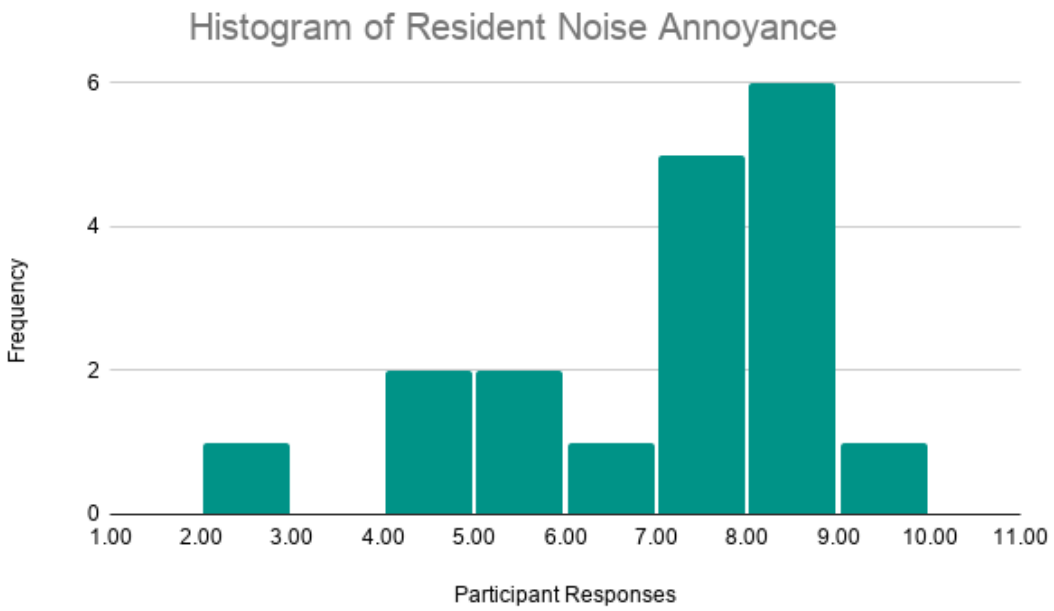

Figure 11: Histogram of survey responses (n = 18) for the question "How much does the noise in your living area/workplace bother you or interrupt daily life?"

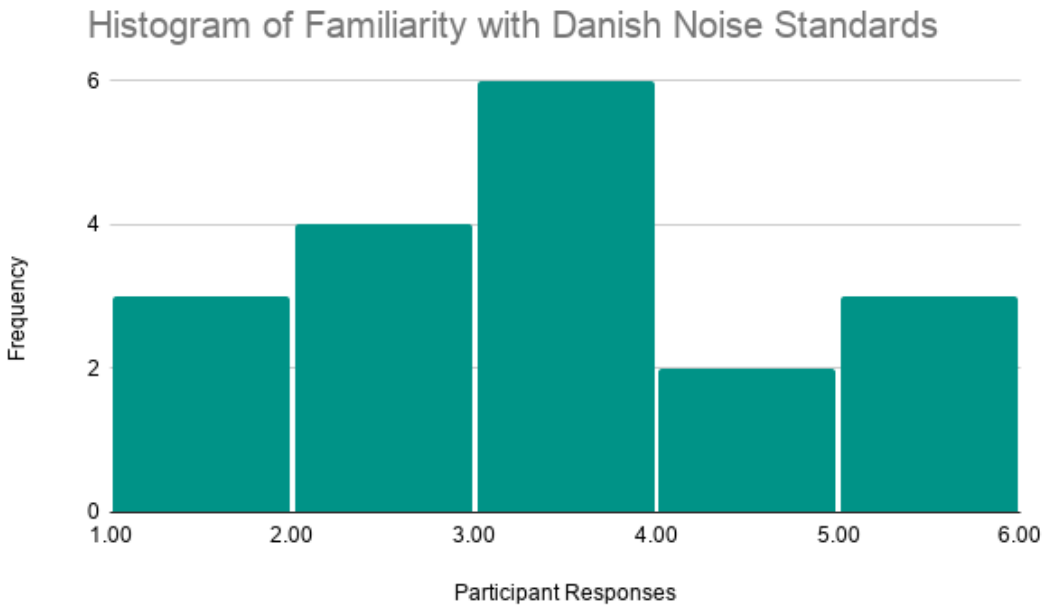

Figure 12: Histogram of survey responses (n = 18) for the question "How familiar are you with the current noise regulations and standards?"

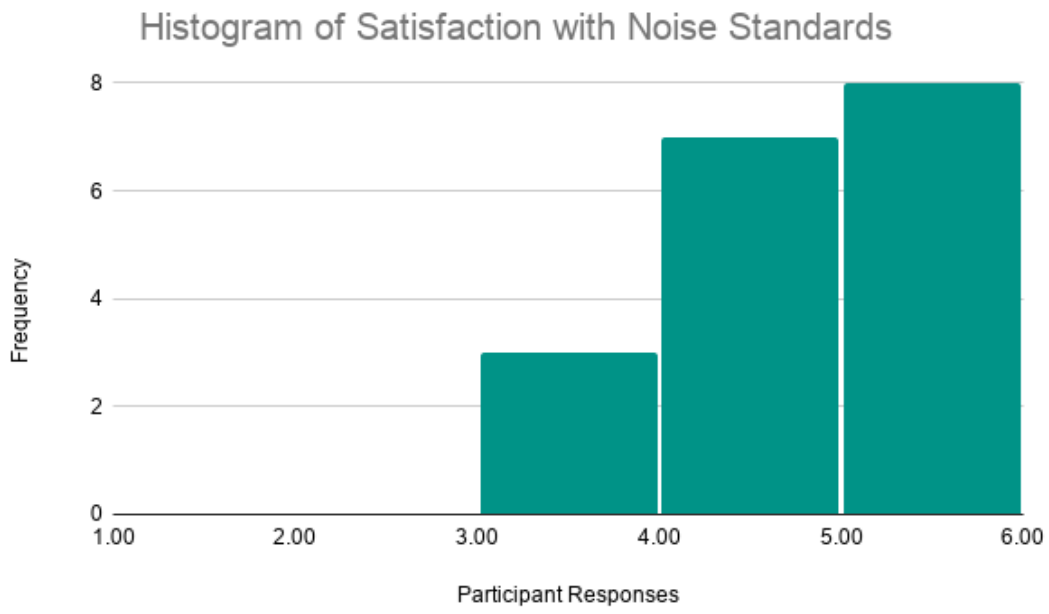

Figure 13: Histogram of survey responses (n = 18) showing participant agreement with the statement that current noise regulations should be stricter.

4.1.2 Interviews

Various noise experts and professionals were interviewed to gather their perspective and understanding of noise and its impact. Interview guides were developed for each person, with some questions tailored to the individual's area of expertise, and others asked everyone to gauge where each person stands on specific topics (Appendices B, C, D, and E). Three professionals were interviewed: a member of Force Technology, a leading audio engineer at Jabra, and a member of Copenhagen's municipality. Additionally, two Inner City residents were interviewed about their personal experiences with noise, particularly low-frequency noise.

4.1.2.1 Jens Oddershede from Force Technology

An industry expert was interviewed to understand the proper LFN measurement techniques and to help identify why cooling and ventilation systems are often problematic. Jens Oddershede works in the noise, acoustic, and vibrations department at Force Technology. His current work focuses on noise propagation and annoyances, particularly with traffic and industrial noise. Force Technology is an independent consultancy and service company that does accredited testing, inspection, and certification of products and technologies. They are also frequently recommended by the municipality to noise-producing parties for advanced measurements. The interview covered the standard noise measurement procedure, the difficulties of measuring LFN, the relation between the municipality and Force Technology, public perception of LFN and regulations, and mitigation strategies.

The interview revealed that Denmark follows a standard procedure for measuring noise based on regulations established in the 1990s, which is upheld today. Oddershede explained this

process and the most important steps, as described in Section 3.2 and Appendix F. Avoiding center points and taking multiple measurements at different locations allows for a more accurate average reading, as noise levels can vary notably in a room. Additionally, he provided a copy of Force Technology's noise meter decibel chart for A-weighting for both low- and high-frequency sound pressure levels, as shown in Figure 14.

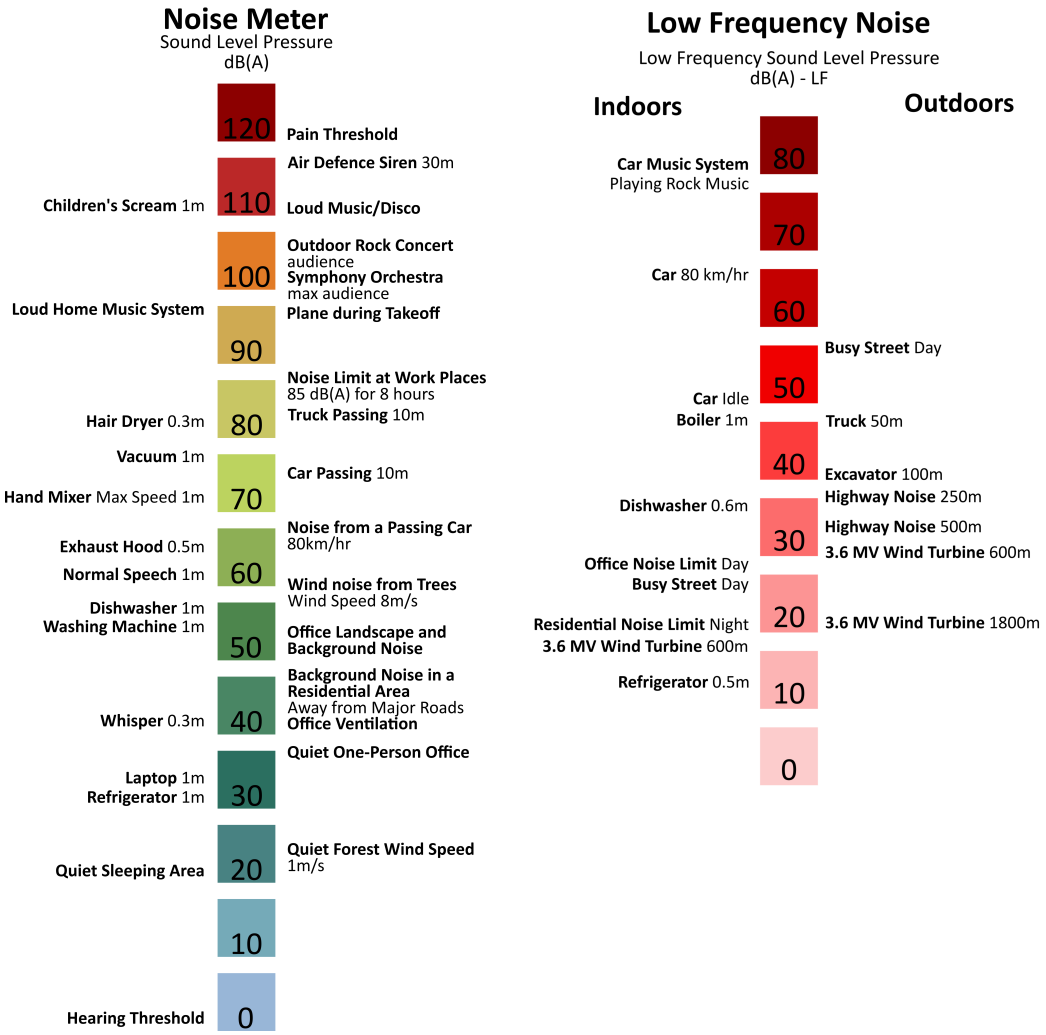

Figure 14: Noise meter charts for sound pressure level in dB(A) [LEFT] and for low-frequency noise in dB(A) [RIGHT], provided by Force Technology and translated from Danish to English.

Furthermore, he discussed the difficulties of measuring low-frequency noise, as LFN is more complex to isolate and measure than medium-frequency noise. The problem is further amplified if the source is outdoors, because other sources need to be quiet for a more accurate measurement. A control measurement is also needed, which is taken when the LFN source is not running, increasing the complexity. Additionally, the interview revealed that the municipality does not measure C-weighted decibels, which best capture LFN, as current regulations are based on A-weighted decibels. This leads to potential discrepancies between perceived annoyance and measured data, as a complainant may feel the LFN, but the A-weighted measurements do not include these lower frequencies. Therefore, the noise may meet regulatory standards, but the

complainant still has an issue with noise levels.

If the case requires it, the party responsible for the noise may contract Force Technology or another accredited company to carry out proper measurements. The typical noise complaint workflow begins when a resident submits an official complaint to the municipality. The municipality does initial measurements using handheld sound level meters. If initial measurements exceed noise pollution limits or are inconclusive, the party responsible for the noise either contracts an independent company, such as Force Technology, that has the technology and expertise to conduct detailed measurements or implements noise-reducing methods. If contracted, Force Technology takes high-precision measurements and provides the municipality with data to determine if the source violates the city's limits. The companies responsible for the noise are incentivized to apply noise mitigation strategies rather than contract another company due to the high costs. The problems of low-frequency noise, including the relation between the municipality and Force Technology, are detailed in Figure 15 below.

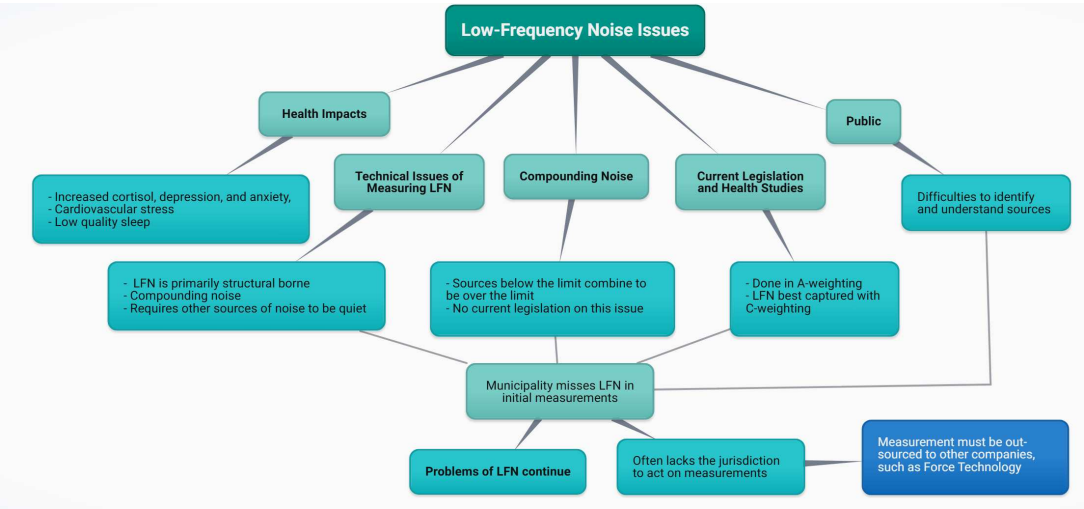

Figure 15: Diagram of the issues surrounding low-frequency noise.

There is a disconnect between the public perception of LFN and current regulations. Due to the limited public awareness of LFN, many citizens lack the understanding to identify noise sources while still recognizing that there is a problem. When the municipality attempts to address these complaints, the issue may be unresolved due to the wrong source being measured or improper weighting being used. Additionally, current regulations do not account for compounding noise sources, resulting in total noise exposure exceeding the threshold, while no single source exceeds it. This creates extra challenges for enforcement, making it more difficult to address complaints. A single party must be responsible for the noise source for proper legal acti. Therefore, if each party is within its limits, the compounding effect cannot be addressed, as there is no regulation concerning the aggregation of multiple sources.

The interview concluded with a discussion of potential mitigation strategies to combat LFN. Oddershede mentioned some common solutions, such as changing fan blade directions to alter airflow patterns, lowering the power level, adding dampeners to system-building contact points, and installing dense, heavy noise barriers near the source. However, he also mentioned that the

effectiveness of these strategies is often limited by the structures and materials on which they are installed.

The interview with Jens Oddershede from Force Technology greatly helped in understanding the standard noise measuring procedures, the challenges of measuring LFN, the interactions between the municipality and Force Technology, the disconnect between the public and regulations, and mitigation strategies for LFN.

4.1.2.2 John Daniel from Jabra

To build on expert perspectives on noise pollution, John Daniel, a lead audio engineer at Jabra, was interviewed. Jabra is a Danish brand that focuses on audio equipment and video-conferencing systems, and Daniel currently researches and develops acoustics and algorithms for voice pickup and noise-cancelling headsets. Daniel built on the difference between A-weighted and C-weighted measurements and how LFN travels differently from other frequencies. This interview highlighted the legislative issues with measuring LFN, the difference between structural-borne and airborne noise, the contrast between sound pressure level and loudness, how humans perceive noise, and the issue of compounding noise.

One of the main takeaways from our interview is that regulations and health studies are based on A-weighted measurements (dB(A)), as it corresponds to the frequency response of the human ear. This also results in official measurements using dB(A), which fails to capture the C-weighted frequencies that best encapsulate LFN. Therefore, current Danish regulations are fundamentally flawed in measuring LFN.

Another important topic discussed was the distinction between structural-borne and airborne noise. LFN mainly comes from structural-borne noise, which happens when a building element vibrates and transmits sound waves. By contrast, airborne noise transmits through the atmosphere and dominates A-weighted measurements. As such, a significant amount of LFN is not captured when completing airborne noise measurements, even if using the proper C-weighted measurement settings. To properly measure LFN from structural vibrations, Daniel recommended accelerometers, which physically attach to the vibrating surface. The municipality does not use accelerometers, but instead, uses handheld devices that focus on airborne noise pollution, as regulations only include A-weighted measurements.

The difference between sound pressure level (SPL) and loudness was also discussed. SPL's are measured in decibels and represent the physical measurement of noise, while loudness is measured in phons and is a subjective measurement scaled to reflect human perception of sound. Daniel argued that loudness is a better determinant of the impact of noise pollution on human hearing and referenced Figure 16 during his explanation.

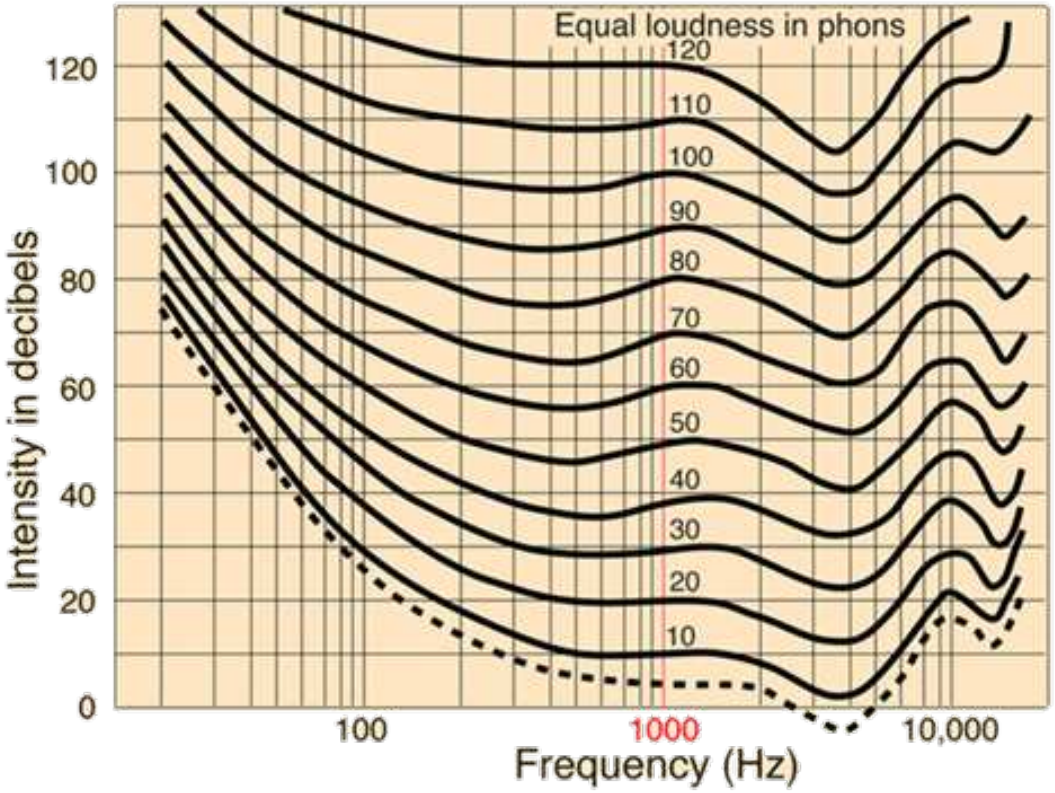

Figure 16: Equal-loudness curves (Nave, n.d.).

Figure 16 illustrates equal loudness curves, demonstrating how human perception of noise varies with frequency. While the sound pressure level (dB) may differ, individuals perceive the same loudness at various noise frequencies. This highlights a significant limitation of relying solely on SPL to evaluate noise pollution. Sound pressure level provides an accurate physical measurement of sound, but does not account for the perceived loudness people experience. Daniel gave the example of using equalization on noise sources, a process in which certain frequencies are altered so that the SPL falls below legal limits, yet the perceived loudness and vibrations still annoy the human ear.

The potential issue of compounding noise was also mentioned, and the lack of regulations surrounding it. Daniel and Oddershede (Force Technology) both agreed that multiple sources, all below the legal noise limits, can combine to produce noise above those limits, and that current regulations fail to account for this. Daniel discussed how the issue has a clear direction and that it is important to start the conversation about it. However, there is not much that can be realistically done, as modern-day standards and regulations are based on A-weighted noise studies that would need to be redone with low-frequency noise levels.

Ultimately, John Daniel revealed the intricate legislative issues surrounding LFN, as standards and current health studies are primarily based on A-weighted measurements, while LFN is best measured using C-weighted measurements. This led to a discussion of structural-borne and airborne noise and then sound pressure level and loudness. Then, from the conversation of loudness, ideas of human perception of noise were brought up, and how that complicates the

issues of compounded noise.

4.1.2.3 Stig Wallin from the Municipality of Copenhagen

After learning the noise experts' perspectives, a member of the municipality was interviewed to help identify any gaps in legislation and the measurement process that were not previously discussed. Stig Wallin, a member of the Sound and Outserving department in the Municipality of Copenhagen, gave us insight into how the municipality handles noise complaints. The department manages environmental noise pollution from all types of sources and receives noise complaints. This interview gave us deeper insight into the complaint process, how the Municipality measures noise, and the jurisdiction they have in handling those complaints. Furthermore, Wallin discussed the psychological aspect of noise and its relation to complaints.

From the interview, the structure of the complaint & municipality measurement processes was thoroughly discussed. Complaints are usually responded to within four to ten days but may be longer depending on the case. Wallin stated that when a noise complaint is filed with the municipality, the complainant is contacted for more details, if possible. Additionally, the complaint is evaluated through a discussion of annoyance during this stage. Key things the Municipality looks for are the duration and frequency of the noise, the time of day it occurs, and whether it exceeds the regulatory standards. Some complaints are resolved without measurement if they clearly fall within the legal threshold. Wallin gave an example of an intermittent noise complaint about a ventilation system that occurred one minute every hour, and when asked if the noise was as loud as a car going by, the residents stated it was lower, inferring the sound is below the limits. If uncertainty remains, the municipality will complete measurements.

The municipality's on-site noise measurements use either the Hand-Held Analyzer Type 2250 Light by Brüel & Kjær or the older model 2238 Mediator by Brüel & Kjær. A-weighted sound levels are collected using LAeq and LA95 settings on the measuring device. The LAeq setting measures all A-weighted frequencies dB(A) collected by the device, while the LA95 isolates A-weighted frequencies that occur during 95% of the test, to focus on the main source, while filtering out spikes. Measurements are taken standing near the source of noise as well as on walls reflecting the noise created by the source. If the results are significantly above the regulatory limits, then the municipality can require the party producing the noise to hire technical experts for thorough testing at the company's expense.

If a noise violation is identified, the municipality cannot prescribe a specific fix but can require the noise-producing party to reduce its noise levels by decreasing operating hours, lowering output, or changing the installation of the noise-producing system. Their process attempts to understand both sides of the complaint to create practical solutions rather than strict enforcement.

Wallin also discussed how ventilation complaints have increased over time due to urban densification in Copenhagen, resulting in the installation of more heating pump systems and large rooftop ventilation units. However, all types of noise complaints, not just those surrounding

cooling and ventilation, have increased as well, with the majority received in the warmer months due to open windows, higher outdoor activity levels, and increased use of cooling and ventilation systems. Other reasons for the increase in cases stem from the growth of the department and the ease and accessibility of filing complaints.

Wallin also brought up individuals' perception of noise. Specifically, the feeling of noise is highly subjective and varies from person to person. Some people can tolerate high levels of noise, while others are annoyed at even low levels. Therefore, psychological factors can be used to reduce perceived noise levels. For instance, the visibility of the source may increase annoyance and amplify its perception and impact over time. Wallin gave an example where, at a concert, a power generator resulted in many noise complaints. However, once they put a carpet in front of the system, people stopped complaining, despite similar noise levels. Simply hiding the noise source may decrease complaints and dissatisfaction with current noise levels. Inversely, if someone comes out to measure and the dB(A) readings are below the limits, but the person still experiences annoyance from LFN, it could aggravate their annoyance further as the measurements do not reflect their experience.

Finally, when asked about current municipality standards, Wallin stated that noise limit regulations are old and should likely be revisited. However, updating these standards is politically difficult. He described the issue as a "hot potato" that nobody wants to touch because changing noise laws impacts businesses, jobs, and urban development. With existing regulations focusing primarily on A-weighted noise, there is a lack of representation for lower-frequency noise and structural vibrations. Wallin stated that the structure vibration limit is nine millimeters, but the municipality does not measure structure movement. Complaints about shaking within homes from external noise have been received, but they do not exceed the structural vibration limits from the building codes. There are no vibration regulations that account for comfort, only structural allowances.

Stig Wallin explained the complaint process from the municipality's perspective and what they do to address these complaints based on the current regulations. He noted a rise in complaints about low-frequency noise from cooling and ventilation systems, indicating this is a growing problem. A particularly memorable point was the discussion of how individuals psychologically perceive noise and its fixes.

4.1.2.4 Union Member

To further assess the opinions of Inner City residents, a member of a local housing association and survey respondent was interviewed about issues they have had with noise, especially a music venue next to their apartment. The main issue discussed was that vibrations caused by the music and a nearby restaurant were extremely disturbing and could be felt more than heard. Drawing on their personal knowledge, the interviewee reinforced the idea that low-frequency noise and vibrations are very difficult to quantify under the current Danish standards. They also described the complaint process with Copenhagen's Municipality as very slow, with some complaints taking years to satisfy. An example that was discussed was when an acquaintance of

the interviewee had to complain for six to eight years about noise from a local restaurant before anything was done about it. They discussed how they felt the municipality tends to side with businesses over people due to the revenue and attention they bring to the city, and that people complaining need to be very insistent and knowledgeable to bring the complaint far enough to see actual consequences.

Ultimately, this interview highlighted the challenges the public faces when making noise complaints, especially regarding low-frequency noise and vibrations. The process often requires technical knowledge and persistence on the complainant's part, leading many to give up early in the complaint process. These findings highlight previously discussed ideas about how a lack of knowledge of residents and businesses and inadequate regulations can lead to complaints not being addressed properly.

4.1.2.5 Survey Respondent

Someone who filled out the survey complained about a cooling and ventilation system located below their apartment. To further investigate this case, they were interviewed, and preliminary measurements of the problem were taken. They said that the noise and vibrations it created made it incredibly difficult for their daughter to sleep at night, as her room is located directly above the noise source. The restaurant's refrigeration system always runs, and additional ventilation systems run at night. When asked whether they ever filed an official complaint, they stated that they only complained to the restaurant, and nothing was done to resolve the issue. The restaurant owners reported to them that there was no problem with the noise from the cooling and ventilation system. Later, a fume hood was added to reduce the smell of food in the building, which further increased the annoyance of noise in the apartment. When asked why they never complained to the municipality, they said they did not want to create an issue or drama since the restaurant claimed it was within the regulations and not a problem. The collected data is shown in Section 4.2.3. Survey Respondent Cooling System Measurement.

This interview provided insight into the lives of people directly affected by the low-frequency noise output by ventilation and cooling systems. Additionally, it demonstrates the challenges residents face when fighting these systems, such as uncertainty about local limits and relying on the businesses generating the problematic noise to address these issues. Overall, this interview reinforces the disconnect between perceived noise and regulations and the need for a better approach to assessing low-frequency noise.

4.1.2.6 Interview Takeaways

Our three technical interviews gave notable insight into the complaint process, from when a citizen files a complaint to the municipality's response, and whether outside expertise is required. Also, these interviews provided us with a better understanding of the measuring procedure, which was used for this project's data collection. One of the main issues is that legislation and health studies are mainly done using A-weighting, which excludes C-weighted measurements. The key points gathered from the technical interviews are as follows:

- Once the municipality measurements are taken, the party responsible for producing noise may need to contact noise measurement experts for further examination if the results are not definitively within the limits, further establishing the relationship between the three groups.
- There are several challenges of measuring low-frequency noise, as current regulations and health studies are based on A-weighting as opposed to C-weighting, which better captures LFN.
- Noise is perceived on both the psychological and physiological levels, leading to a disconnect between measured values and perceived annoyance.
- LFN travels much farther than other frequencies, both structural-borne and airborne, contributing to the issues of measuring low-frequency noise.
- Mitigation strategies can be implemented to best combat low-frequency noise in both residential and commercial areas from installation of the system and throughout its lifecycle.

The two interviews with Inner City residents revealed the problems faced when making complaints, the difficulties in identifying and describing certain sources of noise, and the general lack of information and transparency provided to the citizens. The key points from interviews and surveys from Inner City residents are as follows:

- Individuals are bothered by the current levels of noise, with an increase in the number of complaints.
- Noise complaints are often not fully addressed, regardless of whom they are given to (municipality, restaurants, neighbors, etc.).
- Citizens face many challenges when reporting noise to the municipality and typically require a lot of persistence and time to see changes.
- Citizens are bothered by low-frequency noise and may feel it in their own homes; however, they frequently struggle to identify it as LFN and where it originates.

4.2 Results for Objective 2 – Measuring Noise and Comparing to Residents' Opinions

Objective 2 was completed using the Hand-Held Analyzer Type 2250 from Brüel & Kjær to measure the noise levels in indoor spaces adjacent to two cooling and ventilation systems in the Inner City. This dataset is not designed to replace official measurements, but rather to gain a more complete perspective on the technical aspect of noise. To ensure proper use of the device, the Danish Environmental Protection Agency (EPA) Guidance No. 9/1997 was followed, which outlines methods of selecting measurement points and completing measurements (Appendix F). Additionally, discussions with noise experts who use these tools helped to grasp how to use

the equipment. A-weighted and C-weighted frequencies were simultaneously recorded using the Hand-Held Analyzer. The results were recorded and compared to see the difference between the two weighted measurements.

4.2.1 Control Measurement of the Cooling and Ventilation System

The first measurement was in the kitchen at Miljøpunkt Indre By Christianshavn's office, as there is a ventilation system located outside the window, shown in Figure 17. Per the Danish EPA Guidance No. 9/1997, three locations in the kitchen were measured, as seen in Figure 18. A control measurement was first completed without any cooling or ventilation systems running, as seen in Figure 19.

Figure 17: The cooling and ventilation system whose noise was measured at the Miljøpunkt Indre By & Christianshavn's office

Figure 18: Three measurement points in the Miljøpunkt Indre By & Christianshavn's kitchen.

The data displayed in Figure 18 and Table 1 show a relatively flat trend with average A-weighted noise of approximately 23 dB and average C-weighted noise of approximately 44 dB. As the C-weighted noise is significantly higher, even for the control measurement, it is clear that only looking at A-weighted measurements can lead to incorrect conclusions when measuring LFN, as the C-weighted measurement can capture lower frequencies, leading to the increased noise level compared to the A-weighted.

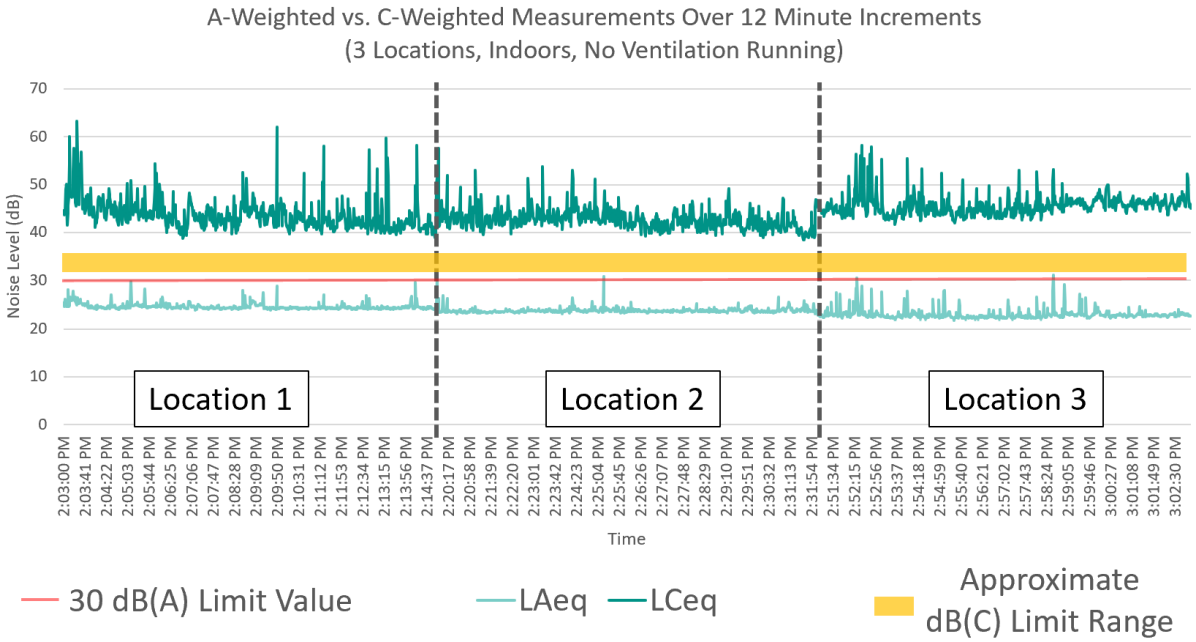

Figure 19: Measurements taken at three locations in the Miljøpunkt Indre By & Christianshavn's office kitchen while the cooling and ventilation system was off.

No Ventilation Running	
	Noise Level (dB)
Average C-Weighted	44.052
Average A-Weighted	23.716

Table 1: Table reporting the averaged data from the graph in Figure 17.

The measurements, whose data are reported in Figure 19 and Table 1, were completed on Friday, April 10th, 2026, between 14.00 and 15.00 as a control measurement. Then, the cooling and ventilation system, including the kitchen refrigerator, was off. The average A-weighted noise level is below the 07.00-22.00 limit outlined in Table 2, which is expected since the system is not running. Table 3 outlines limits for outdoor measurements; however, all the measurements were conducted indoors. Table 4 helps explain the relationship between A-weighted and C-weighted noise from different sources. There is no direct conversion between the two weights, but we can estimate using related references, assuming the trend outlined in Table 4. The lower the noise level in dB(A), the lower the difference is between dB(A) and dB(C) (Ray, 2026). Because all our measured averages are below 60 dB(A), we can assume a dB(C) limit range approximately two to five decibels higher for dB(C) than the 30 dB(A) limit value, indicated by the orange bar in Figure 19 and Figure 20.

Location	**Time Period**	**Limit Value (dB(A))**
Living room	07:00–22:00	30
Living room	22:00–07:00	25
Living room	Night (max level)	40
Office premises	All day	40

Table 2: Limit values for building-transmitted noise measured indoors in living spaces/office spaces, from "Cooling and ventilation regulations in Copenhagen, Appendix 2."

Days	**Times**	**City Center (dB(A))**	**Apartment Building (dB(A))**	**Open/Low Rising Building (dB(A))**
Monday-Friday	07.00-18.00	55	50	45
Saturday	07.00-14.00	55	50	45
Monday-Friday	18.00-22.00	45	45	40
Saturday	14.00-22.00	45	45	40
Sunday and Holidays	07.00-22.00	45	45	40
Everyday	22.00-07.00	40	40	35

Table 3: Limit values for noise exposure measured outdoors at residences/office premises, from "Cooling and ventilation regulations in Copenhagen, Appendix 1."

SOUND SOURCE	DBA (WHAT YOU HEAR)	DBC (ACTUAL ENERGY)	DIFFERENCE
Conversational Speech	60 dBA	62 dBC	Small (~2 dB)
Vacuum Cleaner	70 dBA	75 dBC	Moderate (~5 dB)
Diesel Truck Idling	85 dBA	100 dBC	Large (~15 dB)
Bass-Heavy Music	95 dBA	110 dBC	Very Large (~15+ dB)
Wind Turbine (Near)	50 dBA	70 dBC	Large (~20 dB)

Table 4: Chart displaying the differences between A- and C-weighted values for various sound sources (Ray, 2026).

4.2.2 Running Measurement of the Cooling and Ventilation System

To compare with the control data, measurements at the same positions were taken while the ventilation system was running, with the results shown in Figure 20 and Table 5.

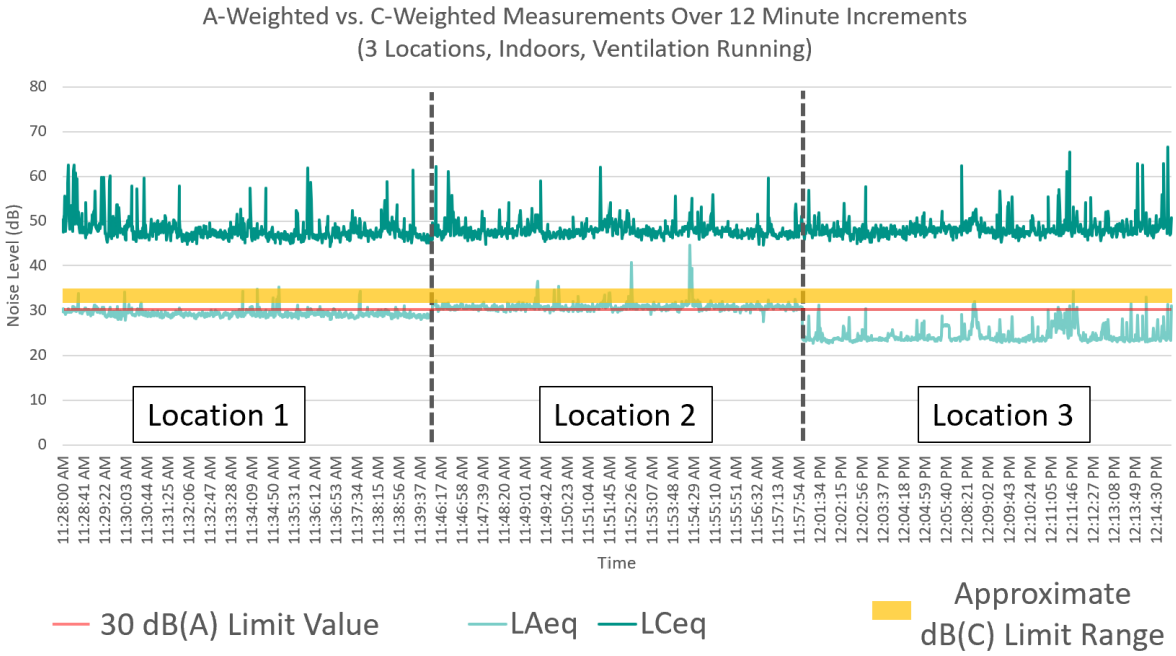

Figure 20: Measurements taken at three locations in the Miljøpunkt Indre By & Christianshavn's office kitchen while the cooling and ventilation system was on.

Ventilation Running	
	Noise Level (dB)
Average C-Weighted	48.122
Average A-Weighted	28.187

Table 5: Table reporting the averaged data from the graph in Figure 20.

The measurements whose data are reported in Figure 20 and Table 5 were completed on Saturday, April 18th, 2026, from 11.00-12.00 while the outside cooling and ventilation system was running. While higher than when the cooling and ventilation system was off, the average A-weighted noise level is still below the 30 dB(A) limit outlined in Table 2 from 07.00-22.00. Additionally, the C-Weighted measurements are well above the assumed approximate dB(C) limit, as indicated by the orange bar in Figure 20.

The graph shows that the first two locations on the A-weighted measurement are much closer to the 30 dB(A) limit, but the third location, high and far away from the source, brings the average below the limit. The C-weighted limit is relatively constant by comparison, suggesting that the LFN produced by the system travels farther. Therefore, it can be inferred that the lower frequencies that are not picked up by the A-weighted measurement are likely leading to the lower levels displayed in Location 3. While the general change in C-weighted measurements when the system is on versus off is not particularly large, the consistency of the data between all locations displays the LFN being captured in all regions of the room.

4.2.3 Survey Respondent Cooling and Ventilation System

During the interview with an Inner City resident, measurements of the cooling and ventilation system of a restaurant below their apartment were taken. Measurements were taken at the apartment level, as seen in Figure 21. Unfortunately, there was not enough time to follow the three measurement methods outlined in the Danish Environmental Protection Agency Guidance No. 9/1997. Instead, two measurements were taken: one in the room most affected by the cooling and ventilation system, and one in a further away room to use as a control, with five minutes of recording time at each location (shorter than required by the Danish Environmental Protection Agency Guidance No. 9/1997). The A- and C-weighted frequencies were recorded using the Hand-Held Analyzer Type 2250, and the results between the two rooms were compared, as seen in Figure 22. The measured data is averaged and reported in Table 6.

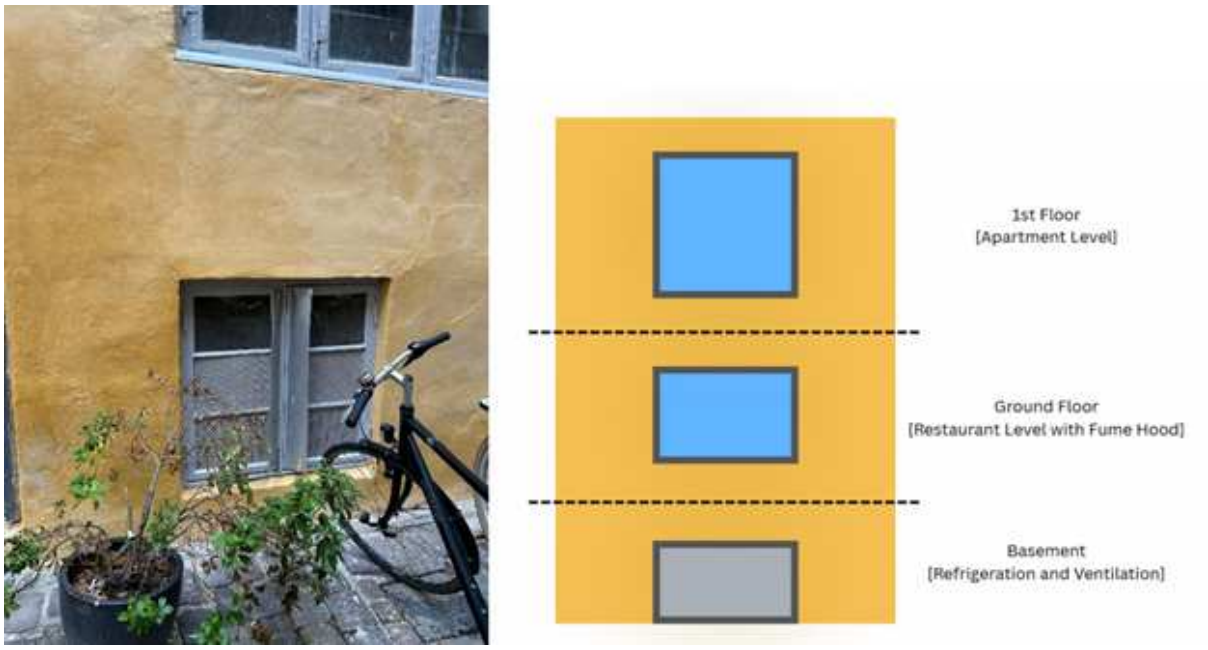

Figure 21: Restaurant refrigeration system behind window on basement level [LEFT] and building diagram [RIGHT]. Measurements were taken on the 1st floor at the apartment level.

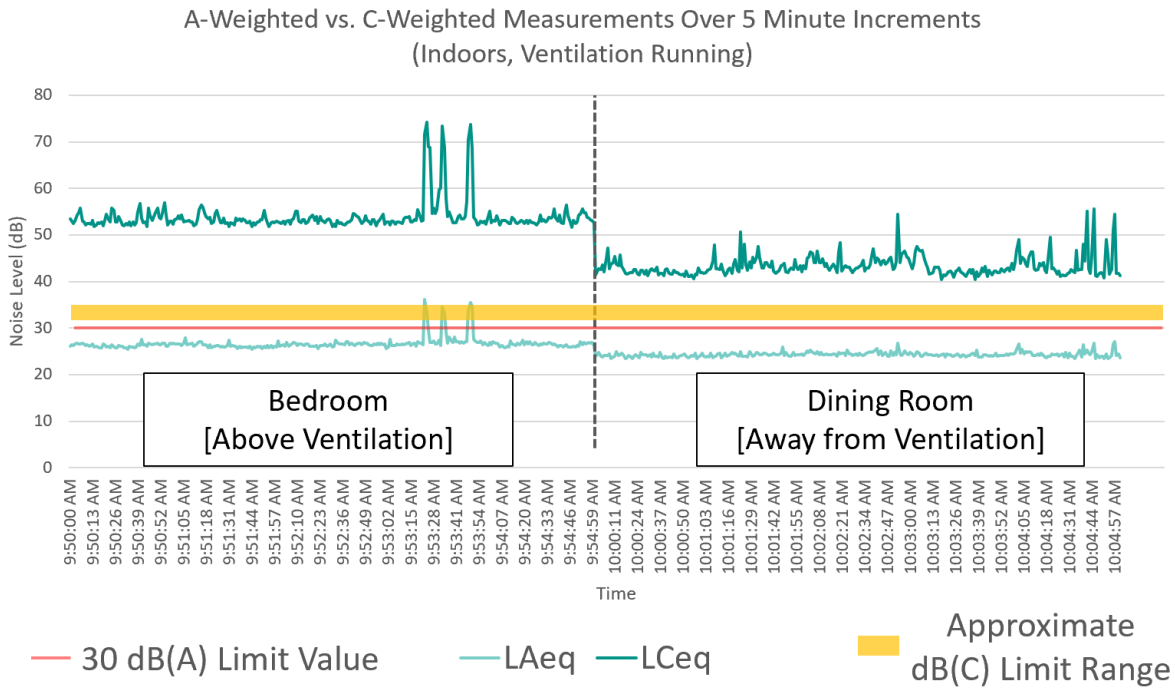

Figure 22: Measurements data from two rooms, one directly above the ventilation/refrigeration system [LEFT], and the other further away from the source [RIGHT].

	Noise Level (dB)
Average Bedroom C-Weighted	53.876
Average Dining Room C-Weighted	43.350
Average Bedroom A-Weighted	26.655
Average Dining Room A-Weighted	24.322

Table 6: Average noise levels corresponding to data from Figure 22.

There is a distinct difference in noise levels between the two rooms, with significantly more LFN above the ventilation system, 54 dB(C), compared to 43 dB(C) in the dining room, far away from the ventilation source, as seen above in Figure 22 and Table 6. The A-weighted measurements have a much smaller difference between the two locations, only about 2.3 dB(A), compared to the C-weighted measurements of approximately 10.5 dB(C). The C-weighted measurements have a much larger difference between the two locations, since, unlike the A-weighted measurements, they capture the LFN outputted by the refrigeration system. Additionally, the C-weighted measurements at both locations are once again well above the assumed approximate limit range, while the A-weighted measurements are below the 30 dB(A) limit at both locations.

In addition to the readings from the noise measurement device, the audio in each room was recorded. In the bedroom above the refrigeration, the fan noise is audible on the recording. In both scenarios, the A-weighted measurements are below the 30 dB(A) daytime limit, yet the fan can still be heard, displaying possible annoyance that can be encountered even if the dB(A) reading is within the limits.

4.3 Results for Objective 3 – Presentation for the Inner City Local Committee and Workgroups and Adding to the Sponsor's Website

Objective 3 combined the findings from Objectives 1 and 2 to compile a presentation for the Inner City Local Committee and workgroups (Appendix G), along with adding materials to the sponsor's website. The presentation was created by using aggregated survey results, interview notes, sample noise measurements, and background research. The survey of the Inner City residents revealed the types of noise they find most bothersome in daily life and a wish for stricter noise regulations. The technical interviews conveyed proper measurement techniques, the complaint process, mitigation strategies, public perception of noise, and how regulations do not capture most low-frequency noise. The measurements indicate a difference between A- and C-weighting noise. We compiled the key findings and presented them to local committee members to highlight the importance of acknowledging LFN.

The presentation focused on human interactions with noise, such as resident complaints, their health impacts, and noise perception, and how it interacts with technical aspects, such as the difficulties of measuring low-frequency noise. We delivered the presentation at a meeting on April 15th, 2026, as seen in Figure 23. The content was well received, and the members

of the workgroups we presented to were interested in the issue and the project results. They asked multiple questions about the project's future steps, as well as recommendations for future projects and goals to combat low-frequency noise. They were also very interested in continuing the project's work, including learning more about low-frequency noise and ways to influence legislation to address the problems of LFN.

Figure 23: Pictures of the presentation given to the Inner City Local Committee.

Information and resources found throughout the project were turned into a webpage on the Miljøpunkt Indre By & Christianshavn website, included in their newsletter, and on social media. The page begins with an abstract that allows readers a quick summary of the project's purpose, goal, and results. The other material attached to the webpage included: the final report, the presentation given to the Local Committee midway through the project, the final presentation slides, and the original project proposal from the sponsor, as shown in Figure 24. The audio recordings taken during the measurements at the survey respondent's home were also incorporated into the final slideshow to exemplify one instance of someone dealing with cooling and ventilation noise.

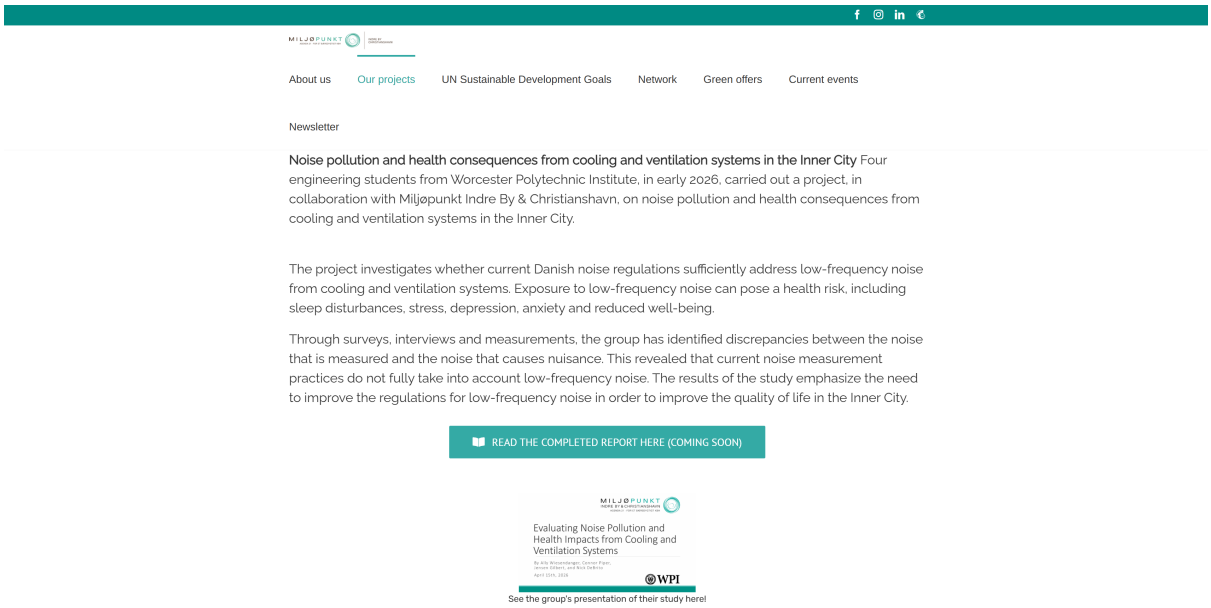

Figure 24: Project material on the sponsor's website.

In conclusion, Objective 3 successfully compiled the results of Objectives 1 and 2 into a presentation delivered to the union leaders of the Inner City district of Copenhagen. We included the slideshow from our presentation in Appendix G. Furthermore, the findings from this project were made accessible on the sponsor's website. This includes the slideshow from the presentation, this report, measurement data, and audio recordings from the data collection.

5 Recommendations

This project sought to help Miljøpunkt Indre By & Christianshavn determine whether current noise standards are sufficient for addressing problematic low-frequency noise (LFN) in the Inner City. Several technical professionals and residents were interviewed about their perspectives, and residents were also surveyed. Cooling and ventilation systems were then measured to compare noise levels with perceived annoyance. Finally, the findings were compiled into a presentation for the Local Committee and workgroups, aimed at informing their members and encouraging policy change. Recommendations were created based on the findings from these objectives, including potential research areas for future interactive qualifying projects, steps Miljøpunkt Indre By Christianshavn can take to take further actions, what the municipality can do now to address LFN, and actions citizens can take to combat LFN.

5.1 Recommendations for Future Interactive Qualifying Project (IQP) and Miljøpunkt Indre By & Christianshavn

Miljøpunkt Indre By & Christianshavn can work with future Interactive Qualifying Project (IQP) teams to explore the legislative, technical, and humanitarian dimensions of compounding noise, structural vibrations, and the persistent challenges posed by low-frequency noise.

After conducting three technical interviews with Jens Oddershede from Force Technology, John Daniel from Jabra, and Stig Wallin from the Municipality of Copenhagen, a main concern brought up was the potential issue of compounding noise sources. This occurs when multiple individual noise sources, each below regulatory limits, combine to exceed acceptable levels. Therefore, it is recommended that future IQP teams look deeper into this by surveying residents to gauge their awareness of compounding noise and the typical number of noise sources they encounter. Additionally, these teams could interview noise pollution experts and city officials to identify effective legislative strategies for addressing compounding noise. Future projects might also incorporate data collected by Miljøpunkt Indre By & Christianshavn, other companies, or the project team, either across Copenhagen or within a controlled environment designed by the project team. The final deliverables could be a presentation or proposal to the sponsor or Municipality on ways to mitigate this issue, either by changing existing regulations to account for this phenomenon or by raising public awareness.

Another issue mentioned by John Daniel of Jabra was that low-frequency noise, unlike dB(A), is spread via structural vibrations rather than air. As such, a future project could focus on measuring structural vibrations from cooling and ventilation systems or transportation using accelerometers and compare these measurements to existing municipality data. This comparison would highlight the difference between structural vibrations and airborne measurements to identify the legislative needs. Future teams could also interview noise pollution experts about their experience measuring structural vibrations and the different mitigation strategies. The final deliverables may include a presentation or infographic that informs local citizens about this issue and the mitigation efforts they could implement in their daily lives.

The interviews revealed many gaps in the current regulations regarding low-frequency noise. Therefore, Miljøpunkt can work with local committee members, workgroups, and citizens to

influence legislation to address these gaps. It is recommended that they use their platform to advocate for changes to include low-frequency noise in the upcoming National Health Law or other regulatory changes. For instance, one change that can be implemented is the addition of using C-weighting for low-frequency noise complaints and their respective regulatory limits. Currently, health studies and legislation focus on A-weighted frequencies, which do not fully capture LFN, especially for structure-borne noise. Therefore, this change will allow the municipality to gauge if LFN complaints need to be officially addressed.

The results also revealed that many issues that arise during the complaint process stem from a lack of public awareness of LFN. Therefore, it is recommended that Miljøpunkt use its platform and connections within the Inner City to inform the public about LFN, such as its health impact, identifying and describing sources, current issues in the legislation, and the proper limits. This can be accomplished through public events, Miljøpunkt's newsletter and website, and general emails to union leaders.

5.2 Recommendations for the Municipality of Copenhagen

One recommendation for the Municipality of Copenhagen is to begin collecting C-weighted measurements simultaneously with the A-weighted ones. The sound level meter used by the municipality, Type 2250 Light, can collect both A- and C-weighted measurements. There is a lack of data and information surrounding C-weighted measurements, as health studies and legislation are in A-weighted. Therefore, the municipality can collect data on a larger scale from a variety of places. The data may be used to highlight the differences between the two weighting types and the importance of using the more applicable one in the given situation. This would allow for a more accurate representation of the problem to hopefully better address LFN complaints. Additionally, the data can be used to influence legislative changes to include LFN or to expand on ideas of equivalent noise.

Another recommendation area for the municipality to look at is compounding noise. Multiple noise sources that fall under regulations may combine to create an intense sound above regulations. However, there is no current legislation that deals with compounding noise, potentially leaving residents to deal with high amounts of noise with no legal way to fix the problem. Therefore, the municipality should investigate ways of dealing with compounding noise, such as different limits for systems that are near one another or have these systems implement certain noise mitigation methods.

An additional recommendation is for the municipality to suggest different noise mitigation strategies to noise-producing parties. These suggestions range from simple, relatively cheap changes to more complex and expensive ones. However, it is important to note that these strategies have limitations, as cooling and ventilation systems for businesses still need to function at a necessary level, such as during working hours. Additionally, the system's location creates further challenges in noise reduction. Therefore, the suggested mitigation strategies should take these variables into account for optimal results. Moreover, these companies are responsible for paying for mitigation methods, which may lead them to forgo certain methods because they are

too expensive to justify. The cooling and ventilation systems most in need of these changes are larger systems closer to residential areas, as these impact citizens daily.

One of the ideal methods to limit noise is to reduce the source power, as this lowers noise and vibrations, although testing is required to ensure the business still meets its needs at the reduced level. Other examples of mitigation methods include using dampeners, acoustic foam, noise barriers, system suspension, and changing the fan direction. Many of these changes reduce structural-borne vibrations by adding material, such as rubber dampeners or foam, which absorb and dissipate energy to reduce the amount of vibrational energy the structure receives. Suspension of the system avoids contact between the system and the building, but this would require higher costs and time to implement. As previously discussed, reducing structural-borne vibrations lessens the effects and spread of low-frequency noise, leading to fewer problems.

5.3 Recommendations for Citizens

From a citizen's perspective, there are a variety of recommendations to help with noise pollution, including temporary methods, cooling and ventilation alterations, and support for legislative changes. The simplest way to decrease noise pollution from cooling and ventilation systems is run the system at a lower power, which benefits everyone while diminishing noise and vibrations, without requiring expensive repairs or changes. Dampeners can also be added on the contact points between the system and buildings to limit the vibrations the building receives. Adding acoustic foam around the source reduces noise by changing sound energy from vibratory energy of air particles to heat energy through dissipation. Noise barriers, or sound walls or acoustic barriers, are large structures designed to reflect, absorb, or diffract noise. Changing the fan direction may also lower noise by altering the airflow pattern. This wide range of options gives individuals the flexibility to implement them in their own systems.

If a resident has had concerns over low-frequency noise, it is best to reach out to the municipality, local union members, or Miljøpunkt to share their experience. The more examples of LFN creating disturbances, the more motivation there would be politically to create change. Furthermore, a petition can be created to change current noise regulations, which requires a minimum of 2,500 signatures for a political representative to support it, and 50,000 signatures for parliament to consider it as a law.

These recommendations offer encouragement for potential future project ideas, so that different areas of low-frequency noise pollution can be further examined. Additionally, Miljøpunkt Indre By & Christianshavn can work with unions, local committees, and the municipality to persuade parliament to consider legislative changes to address low-frequency noise pollution. The municipality may recommend more tailored noise mitigation strategies, collect C-weighted measurements for data, and address compounding noise. Finally, the public may sign petitions for legislative action and implement simple noise mitigation measures in their own homes.

6 Conclusion

As a result of our research throughout this project, the importance of comprehensive regulations that consider an ever-changing urban environment in relation to human health and perception became very clear. Urbanization has increased noise levels, especially from traffic, recreation, construction, and neighborhood areas. Additionally, the number and scale of cooling and ventilation systems have increased, resulting in residents experiencing higher levels of annoyance from the low-frequency noise (LFN) output by these systems. Therefore, future regulations should include proper measuring methods and standards that account for low-frequency noise, as they currently do not. The goal of this project was to assist Miljøpunkt Indre By Christianshavn in evaluating whether the current Danish noise measurement standards adequately account for low-frequency environmental noise in Copenhagen's Inner City district. Specifically, we focused on low-frequency noise generated by cooling and ventilation systems, as LFN exposure has numerous adverse health effects and is an underrepresented annoyance to residents.

This was completed through three main objectives. The first objective assessed opinions of Inner City residents, the Municipality of Copenhagen, and noise experts about cooling and ventilation noise, particularly in commercial and residential areas. This involved surveying Inner City residents about their opinions on current noise levels, notable noise sources, and current noise-related legislation. Furthermore, five individuals with various backgrounds were interviewed: a member of Force Technology, a member of Jabra, a member of the Municipality of Copenhagen, and two Inner City residents. The surveys and interviews revealed that current standards and regulations are based on A-weighted noise, which does not fully encompass the "feeling" of low-frequency noise. Furthermore, several technical challenges during the measurement process were revealed. This includes how LFN is primarily composed of structural-borne noise, which requires specialized equipment to measure, and how other sources of noise must be kept quiet during this process. This leads to issues for the municipality, as they lack the proper equipment to measure structural-borne noise. Additionally, misidentified noise sources lead the municipality to measure the wrong noise and never identify the real issue.

The second objective measured and analyzed noise in two indoor spaces adjacent to cooling and ventilation systems to evaluate differences in the A- and C-weighted levels, and then compared those differences to the perceived annoyance identified in the first objective. To accurately collect data, the Danish Environmental Protection Agency Guidance No. 9/1997 and information gathered from interviews in Objective 1 were followed. A Hand-Held Analyzer Type 2250 measured the systems and found a large difference between the A- and C-weighted measurements, with the C-weighted measurements changing more compared to the A-weighted measurements when the cooling and ventilation system was on. This further shows that LFN is best captured using C-weighted as opposed to the currently standard A-weighted.

The third objective compiled the information obtained from the first two objectives into a presentation for the Local Inner City Committee and workgroups, and such information to the sponsor's website. The presentation focused on discrepancies between measured noise pollution and public annoyance, the technical issues of LFN, the municipality's role in measuring noise,

and data collected in Objective 2. This presentation highlighted the need for an update to legislation, along with educating members of the public to help advocate for these changes. The resources added to the sponsor's website also inform the public about noise pollution, such as health impacts and ways to get involved to influence legislation.

It is recommended that the Municipality of Copenhagen begin collecting C-weighted measurements to have access to more data to use when forming legislation and standards. New legislation should include more on low-frequency noise, such as measurement methods, noise limits, and applications it should be used for. For citizens negatively impacted by LFN, it is recommended to reduce the source power level or install dampeners/noise barriers if possible. It is also recommended that citizens reach out to Miljøpunkt or a local union member about their experience with noise and how they can get involved in political efforts. Future work should examine the issues of compounding noise and the public impact of structural vibrations, as they are both ongoing problems with little to no regulations addressing either.

We believe that this project can be used to support future, more in-depth projects on Inner City noise or to advocate for legislative changes that address the issues associated with low-frequency noise in Copenhagen.

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8 Appendices

A Surveys for Inner City Residents in English and Danish

A.1 Survey for Inner City Residents in English

The following questions are a part of a survey for general residents of the Inner City district. The questions are designed to gauge the community's opinion on the current noise levels in the surrounding area.

Preamble: We are a group of students from Worcester Polytechnic Institute working with Miljøpunkt Indre By & Christianshavn to inform the public of the Inner City district of Copenhagen about the effects of low-frequency noise from cooling and ventilation systems. We would be grateful if you could complete this short survey to answer a few questions about your experience with noise in the surrounding area. You are free to skip any questions in the survey that you prefer not to answer.

What language do you prefer?/Hvilket sprog foretrækker du?

Dansk – Takes responder to the Danish survey (8.1.2)

English – Takes responder to the English survey (8.1.1)

Investigators: Ally Wiesendanger, Connor Piper, Jensen Gilbert, and Nicholas DeBrito

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For more information about this research or about the rights of research participants, or in case of research-related injury, contact:

Any of the investigators listed at the top of the first page and/or the following people:

IRB Manager Ruth McKeogh:

Tel. +1 508 831-6699, Email: irb@wpi.edu

Human Protection Administrator Gabriel Johnson:

Tel. +1 508-831-4989, Email: gjohnson@wpi.edu

Your participation in this research is voluntary. Your refusal to participate will not result in any penalty to you or any loss of benefits to which you may otherwise be entitled. You may decide to stop participating in the research at any time without penalty or loss of other benefits. The project investigators retain the right to cancel or postpone the experimental procedures at any time they see fit.

By selecting "Agree" below, you acknowledge that you have been informed about and consent to be a participant in the study described above.

1. Agree
2. Disagree – End survey

1. Would you like your responses to remain confidential? If 'No', we may attribute your comments to you in our publicly available research, as detailed in the 'preamble' section above.

a. Yes

b. No

2. What is your age?
    a. [Free response] – Responders must be at least 18 years old to continue

3. How much does the noise in your living area/workplace bother you or interrupt daily life?
    a. [Scale of 1–10]
        i. 1 – noise is not noticeable or does not affect daily life
        ii. 10 – noise is constantly bothering/interrupting daily life, to the point where it is unbearable.

4. What sources of noise do you notice the most? (transportation, construction, cooling, ventilation, etc.?)
    a. [Free response]

5. How familiar are you with current noise regulations and standards?
    a. [Scale of 1–5]
        i. 1 – Not at all
        ii. 5 – Very familiar

6. With the knowledge you have about said standards, where do you stand on them? Should they be stricter or more lenient?
    a. [Scale of 1–10]
        i. 1 – More lenient
        ii. 10 – More strict

7. Have you ever complained about noise?

    a. Yes

    b. No

8. If [Yes] to the previous question, who did you complain to, and did it make a difference?
    a. [Free response]

9. Could you be interested in having noise measured in and around your home? We are selecting locations that are specifically impacted by cooling and ventilation noise pollution. (If yes, we might contact you to inquire further).

a. Yes

b. No

10. If [Yes] to the previous question, what specifically would you be interested in having measured?

    a. [Free response]

11. Could you be interested in a follow-up interview/focus group?

    a. Yes

    b. No

12. If [Yes] to either of the previous two questions, what is your contact information (email, phone number, WhatsApp)? By providing your contact information here, we may contact you based on the answers provided.

If you are interested in following the project, please visit the Miljøpunkt Indre By & Christianshavn Website for future updates.

Thank you for your participation!

A.2 Survey for Inner City Residents in Danish

Projektgruppe: Ally Wiesendanger, Connor Piper, Jensen Gilbert, and Nicholas DeBrito
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For yderligere information om denne undersøgelse, om dine rettigheder som deltager, eller i tilfælde af skader relateret til undersøgelsen, kontakt:
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Din deltagelse i denne undersøgelse er frivillig. Hvis du ikke ønsker at deltage, medfører ingen sanktioner eller tab af ydelser, som du muligvis ellers vil være berettiget til. Du kan til enhver tid afbryde din deltagelse i undersøgelsen, uden konsekvenser eller tab af rettigheder. Projektgruppen forbeholder sig retten til at aflyse eller udskyde forskningsaktiviteterne, hvis det vurderes som nødvendigt.

Ved at vælge "Accepter" nedenfor bekræfter du, at du er blevet informeret om og giver dit samtykke til at deltage i undersøgelsen beskrevet ovenfor.

1. Accepter
2. Afvis – Afslut spørgeskema

Foretrækker du, at dine svar forbliver fortrolige? Hvis "Nej", vil vi muligvis tilskrive dine kommentarer til dig i vores offentligt tilgængelige forskning, som beskrevet i forordet ovenfor.

a. Ja
b. Nej

Hvor gammel er du?

Andet spørgsmål: I hvilken grad generer eller forstyrrer støj dig i dit hjem eller arbejdsplads?

a. [Scale of 1–10]
   i. Støj er ikke mærkbar og/eller påvirker ikke min hverdag :1
   ii. Støj forstyrrer/generer mig konstant min hverdag, i en sådan grad, at det er uudholdeligt :10

Hvilke typer støj lægger du mest mærke til (transport, byggeri, køling, ventilation osv.)

Hvor bekendt er du med de nuværende regler, lovkrav og/eller grænseværdier for støj?

a. [Scale of 1–5]
    i. Slet ikke: 1
    ii. Meget velkendt: 5

På baggrund af den viden du har om disse regler og grænseværdier, hvad er dit standpunkt? Bør de være strengere eller mere lempelige?

a. [Scale of 1–5]
    i. Mest Lempelige: 1
    ii. Mest Strenge: 5

Har du nogensinde klaget over støj?

a. Ja

b. Nej

Hvis (Ja) til det foregående spørgsmål, hvem klagede du til, og gjorde det en forskel?

Kunne du være interesseret i at få støj målt i eller omkring dit hjem? Vi udvælger steder, som er særligt påvirket af støjforurening fra ventilations- og køleanlæg. (Hvis ja, vil vi gerne kontakte dig for opfølgning).

a. Ja

b. Nej

Hvis (Ja) til det foregående spørgsmål, hvad ville du specifikt være interesseret i at have målt?

Er du interesseret i at deltage i et opfølgende interview eller en fokusgruppe?

a. Ja

b. Nej

Hvis (Ja) til et af de foregående spørgsmål, venligst udfyld dine kontaktoplysninger (email, telefonnummer, WhatsApp). Ved at angive dine kontaktoplysninger, vil vi muligvis kontakte dig på baggrund af dine svar.

B Force Technology Interview Guide

The following questions are a part of a potential interview for members of Force Technology. The questions are designed to gauge the opinions of people who have worked more closely with noise pollution measurements.

Preamble: We are a group of students from Worcester Polytechnic Institute working with Miljøpunkt Indre By & Christianshavn to inform the public of the Inner City district of Copenhagen about the effects of low-frequency noise from cooling and ventilation systems. We would be grateful if you would participate in the following interview to answer a few questions about your experience with noise in the surrounding area. You are free to skip any questions that you prefer not to answer, and may terminate the interview at any time.

Your participation in this research is voluntary. Your refusal to participate will not result in any penalty to you or any loss of benefits to which you may otherwise be entitled. You may decide to stop participating in the research at any time without penalty or loss of other benefits. The project investigators retain the right to cancel or postpone the experimental procedures at any time they see fit.

By verbally agreeing, you acknowledge that you have been informed about and consent to be a participant in the study described above.

1. Would you like your responses to remain confidential? If 'No', we may attribute your comments to you in our publicly available research, as detailed in the 'preamble' section above.
    a. Yes
    b. No

2. Do you consent to the recording of this interview for the purpose of transcribing the conversation?
    a. Yes
    b. No

3. What is your background/experience with measuring noise?
    a. [Free response]
        i. Projects, etc.

4. How have you been involved in measuring noise pollution/responding to noise complaints?
    a. [Free response]
        i. What measuring devices and methods do you use?

ii. What kinds of environments and sources do you measure the most?

iii. Have you noticed a discrepancy between some measuring methods vs. others? (leading into LFN)

5. What are your current opinions on noise regulations and standards?
    a. [Free response]
    i. Do you feel any major areas regarding noise are lacking in current regulations and standards?
        1. Yes
        2. No
        3. [If Yes] What areas?
    ii. Is the current standard for addressing annoying or loud noise sufficient?
        1. Yes, explain
        2. No, explain
        3. [If No] How do you feel the standard failed?

6. [**Related to above**] Is the current standard sufficient for addressing specifically cooling and ventilation noise pollution?
    a. Yes
    b. No
    c. [If Yes] What areas do you believe best address the problems of cooling and ventilation noise pollution?
    d. [If No] What areas do you believe are lacking in the current standards?

7. In your experience, are noise pollution issues with cooling and ventilation more related to equipment/system design, building layout, urban city design/planning, or something else?
    a. [Free response]

8. What mitigation strategies for cooling and ventilation systems (or low frequency noise) do you think are the most effective?
    a. [Free response]

C Municipality Interview Guide

The following questions are a part of a potential interview for members of Copenhagen's Municipality who have worked with noise measurements and regulations. The questions are designed to gauge the opinions of people who have worked more closely with noise pollution regulation and standards.

Preamble: We are a group of students from Worcester Polytechnic Institute working with Miljøpunkt Indre By & Christianshavn to inform the public of the Inner City district of Copenhagen about the effects of low-frequency noise from cooling and ventilation systems. We would be grateful if you could complete this short survey to answer a few questions about your experience with noise in the surrounding area. You are free to skip any questions in the survey that you prefer not to answer.

Your participation in this research is voluntary. Your refusal to participate will not result in any penalty to you or any loss of benefits to which you may otherwise be entitled. You may decide to stop participating in the research at any time without penalty or loss of other benefits. The project investigators retain the right to cancel or postpone the experimental procedures at any time they see fit.

By verbally agreeing, you acknowledge that you have been informed about and consent to be a participant in the study described above.

1. Would you like your responses to remain confidential? If 'No', we may attribute your comments to you in our publicly available research, as detailed in the 'preamble' section above.
    a. Yes
    b. No

2. Do you consent to the recording of this interview for the purpose of transcribing the conversation?
    a. Yes
    b. No

3. How have you been involved in responding to noise complaints?
    a. [Free response]
        i. What measuring devices and methods do you use?
        ii. On average, how many people have made formal noise complaints?
            1. Per week?
            2. Per day?

iii. What is the course of action if they make a complaint?

iv. Do people have their noise complaints satisfied?

4. What are your current opinions on noise regulations and standards?
    a. [Free response]

    i. Do you feel any major areas regarding noise are lacking in current regulations and standards?

        1. Yes
        2. No
        3. [If Yes] What areas?

    ii. Is the current standard for addressing annoying or loud noise sufficient?

        1. Yes, explain
        2. No, explain
        3. [If No] How do you feel the standard failed?

5. **[Related to above]** Is the current standard sufficient for addressing specifically cooling and ventilation noise pollution?

    a. Yes
    b. No

    If Yes What areas do you believe best address the problems of cooling and ventilation noise pollution?

    If No What areas do you believe are lacking in the current standards?

6. In your experience, are noise pollution issues with cooling and ventilation more related to equipment/system design, building layout, urban city design/planning, or something else?
    a. [Free response]

7. What mitigation strategies do you think are the most effective?
    a. [Free response]

D John Daniel Interview Guide

The following questions are a part of a potential interview for John, a graduate student who works closely with noise. The questions are designed to gauge the opinions of someone who has worked closely with noise.

Preamble: We are a group of students from Worcester Polytechnic Institute working with Miljøpunkt Indre By & Christianshavn to inform the public of the Inner City district of Copenhagen about the effects of low-frequency noise from cooling and ventilation systems. We would be grateful if you would participate in the following interview to answer a few questions about your experience with noise. You are free to skip any questions that you prefer not to answer, and may terminate the interview at any time.

Your participation in this research is voluntary. Your refusal to participate will not result in any penalty to you or any loss of benefits to which you may otherwise be entitled. You may decide to stop participating in the research at any time without penalty or loss of other benefits. The project investigators retain the right to cancel or postpone the experimental procedures at any time they see fit.

By verbally agreeing, you acknowledge that you have been informed about and consent to be a participant in the study described above.

1. Would you like your responses to remain confidential? If 'No', we may attribute your comments to you in our publicly available research, as detailed in the 'preamble' section above.
    a. Yes
    b. No

2. Do you consent to the recording of this interview for the purpose of transcribing the conversation?
    a. Yes
    b. No

3. What is your background/experience with measuring noise?
    a. [Free response]
        i. Projects, research, etc.

4. What led you to research noise? What were your main motivations?
    a. What aspects of noise most interest you?

5. How have you been involved in measuring noise?
    a. [Free response]
        i. What measuring devices and methods do you use?
        ii. What kinds of environments and sources do you measure the most?
        iii. Have you noticed a discrepancy between some measuring methods vs. others? (leading into LFN)

6. What are your current opinions on noise regulations and standards?
    a. [Free response]
        i. Do you feel any major areas regarding noise are lacking in current regulations and standards?
            1. [Yes/No]
            2. [If Yes] What areas?
        ii. Is the current standard for addressing annoying or loud noise sufficient?
            1. Yes, explain
            2. No, explain
            3. [If No] How do you feel the standard failed?

7. [**Related to above**] Is the current standard sufficient for addressing specifically cooling and ventilation noise pollution?

    Yes/No

    If Yes What areas do you believe best address the problems of cooling and ventilation noise pollution?

    If No What areas do you believe are lacking in the current standards?

8. In your experience, are noise pollution issues with cooling and ventilation more related to equipment/system design, building layout, urban city design/ planning, or something else?
    a. [Free response]

9. What mitigation strategies for cooling and ventilation systems (or low-frequency noise) do you think are the most effective?
    a. [Free response]

E Inner City Resident Interview Guide

The following questions are a part of a potential interview for members of the Inner City public. The questions are designed to gauge the opinions of people who have worked more closely with noise pollution measurements.

Preamble: We are a group of students from Worcester Polytechnic Institute working with Miljøpunkt Indre By & Christianshavn to inform the public of the Inner City district of Copenhagen about the effects of low-frequency noise from cooling and ventilation systems. We would be grateful if you would participate in the following interview to answer a few questions about your experience with noise in the surrounding area. You are free to skip any questions that you prefer not to answer, and you may terminate the interview at any time.

Your participation in this research is voluntary. Your refusal to participate will not result in any penalty to you or any loss of benefits to which you may otherwise be entitled. You may decide to stop participating in the research at any time without penalty or loss of other benefits. The project investigators retain the right to cancel or postpone the experimental procedures at any time they see fit.

By verbally agreeing, you acknowledge that you have been informed about and consent to be a participant in the study described above.

1. Would you like your responses to remain confidential? If 'No', we may attribute your comments to you in our publicly available research, as detailed in the 'preamble' section above.
    a. Yes
    b. No

2. Do you consent to the recording of this interview for the purpose of transcribing the conversation?
    a. Yes
    b. No

3. What are your current opinions on noise regulations and standards?
    a. [Free response]
        i. Do you feel any major areas regarding noise are lacking in current regulations and standards?
            1. [Yes/No]
            2. [If Yes] What areas?
        ii. Is the current standard for addressing annoying or loud noise sufficient?

1. Yes, explain
2. No, explain
3. [If No] How do you feel the standard failed?

4. [**Related to above**] Is the current standard sufficient for addressing specifically cooling and ventilation noise pollution?

   Yes/No

   If Yes What areas do you believe best address the problems of cooling and ventilation noise pollution?

   If No What areas do you believe are lacking in the current standards?

5. In what ways does noise impact your daily life?
   a. [Free response]

6. Did you ever complain about noise before?
   a. If so, who did you complain to, and did it make a difference?
   b. What was the process of filing an official noise complaint?

F Noise Measurement Process

The following is a starter guide to operating the Brüel & Kjær Hand-Held Analyzer Type 2250 Light and Type 2250, as seen in Figure 25.

Figure 25: Brüel & Kjær Hand-Held Analyzer Type 2250 Light [LEFT] and Type 2250 [RIGHT].

1. Power on the device using the large button below the display.
2. There is a stylus located on the upper right side of the device, indicated by the green dot.
3. Using the stylus, navigate the display and select the “Broadband” tab at the bottom of the display.
4. A bar graph will display the reading of the LAF value regardless of whether the device is

recording or not.

5. Below the graph is a series of measurement values, such as LAeq, LCeq, LAmax, etc., that can be changed by selecting the name of the measurement. These values will only be displayed while actively recording. The information logged will be independent of the displayed information, so the desired measurements do not have to be on screen to be logged.

6. An SD card can be placed into the bottom of the device under the hinged cover. Select the desired SD card to store the logged measurements by selecting the SD name at the top of the display.

7. By selecting the three-line icon in the bottom left of the display, you can access the setup menu. There are a variety of measurement settings that can be defined, including the following:

    a. The device can be put into manual mode, which allows you to manually start and stop the recording, or it can be in automatic mode, where the recording will stop after a specified amount of time.

    b. The desired frequency and range can be selected to capture the proper weighted measurements.

8. Once the device is placed in the desired location, you can begin the recording by pressing the pause/play button located just above the display. In order to pause the recording, press the button again. This will only pause the recording. Once you press play again, the recording will continue.

9. Once you are finished recording, pause the recording and press the button to the right of the pause/play button to download the data to the SD card.

10. When the measurement is completed, replace the stylus in the device and press the power button to turn it off.

BZ-5503 Measurement Partner Suite

- To extract the logged data, the software called “BZ-5503 Measurement Partner Suite” must be downloaded on your computer.
- Once installed, link the device to your computer using the micro-USB port at the bottom of the device.
- After plugging the device into the computer, open the software.
- The device name should appear under the “DEVICE” tab on the left side of the screen. Select the device drop-down and select the desired SD card.

- Select the desired file name from the SD card and double-click to download the file to your device. After double-clicking, you will be prompted to send the file to a folder in the archive.
- Access the file under the "ARCHIVE" tab on the left side of the screen.
- To view a preview of the logged data, select the button outlined in red in Figure 26.
- To export the data to a .csv file, select the "Export" button in the top left of the screen, located next to the mail icon.

Figure 26: Graph display button located in the top right of the BZ-5503 Measurement Partner Suite.

G Committee Presentation

MILJØPUNKT
INDRE BY & CHRISTIANSHAVN
AGENDA 21 · FOR ET BÆREDYGTIGT KBH

Evaluating Noise Pollution and Health Impacts from Cooling and Ventilation Systems

By Ally Wiesendanger, Connor Piper, Jensen Gilbert, and Nick DeBrito

April 15th, 2026

WPI

Meet the Team

Students from Worcester Polytechnic Institute:

Nicholas DeBrito
- Mechanical Engineering

Jensen Gilbert
- Aerospace Engineering

Connor Piper
- Architectural Engineering

Ally Wiesendanger
- Mechanical Engineering

Urban Noise Sources

Main Cooling and Ventilation Sources

Traffic

Construction

Social

Restaurants
Cafés
Events

Industrial

Neighborhood

Cooling and Ventilation Noise Pollution

Cooling and Ventilation Systems operate continuously

Primary Sources

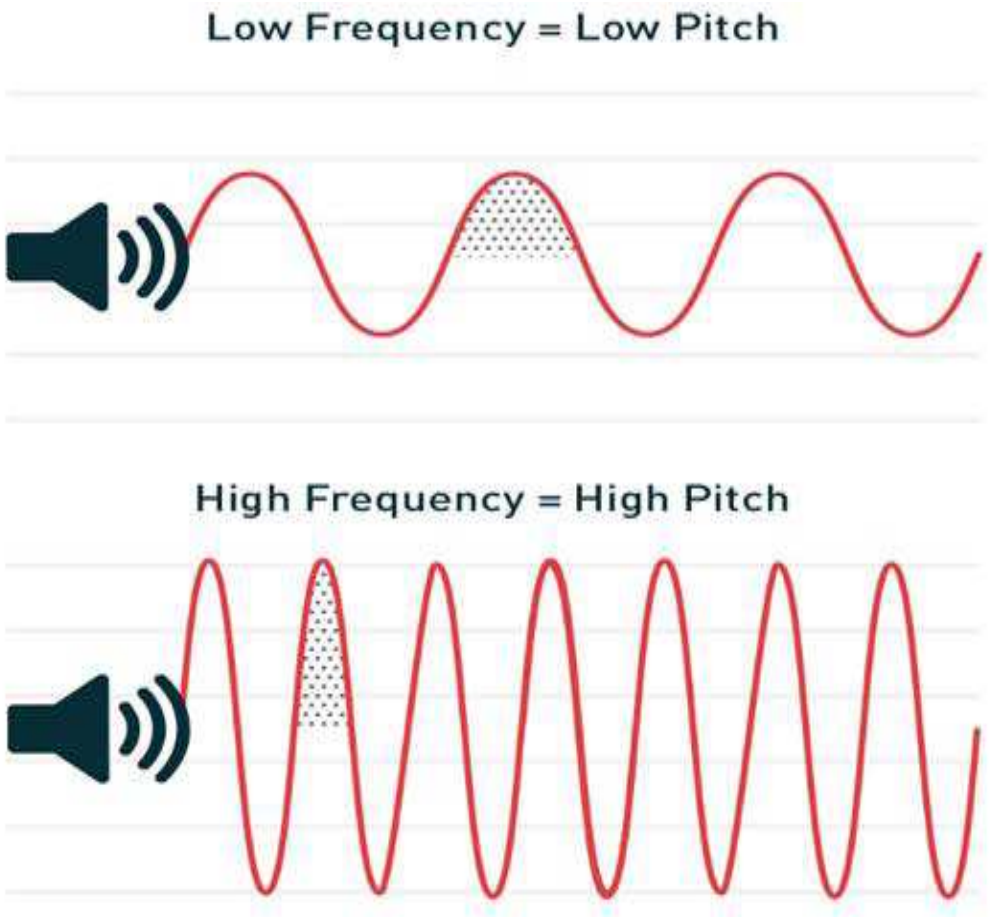
- Fans, compressors, motors
- Airflow in ducts

Spreads Through Nearby Structures

- Sounds propagate via vibration

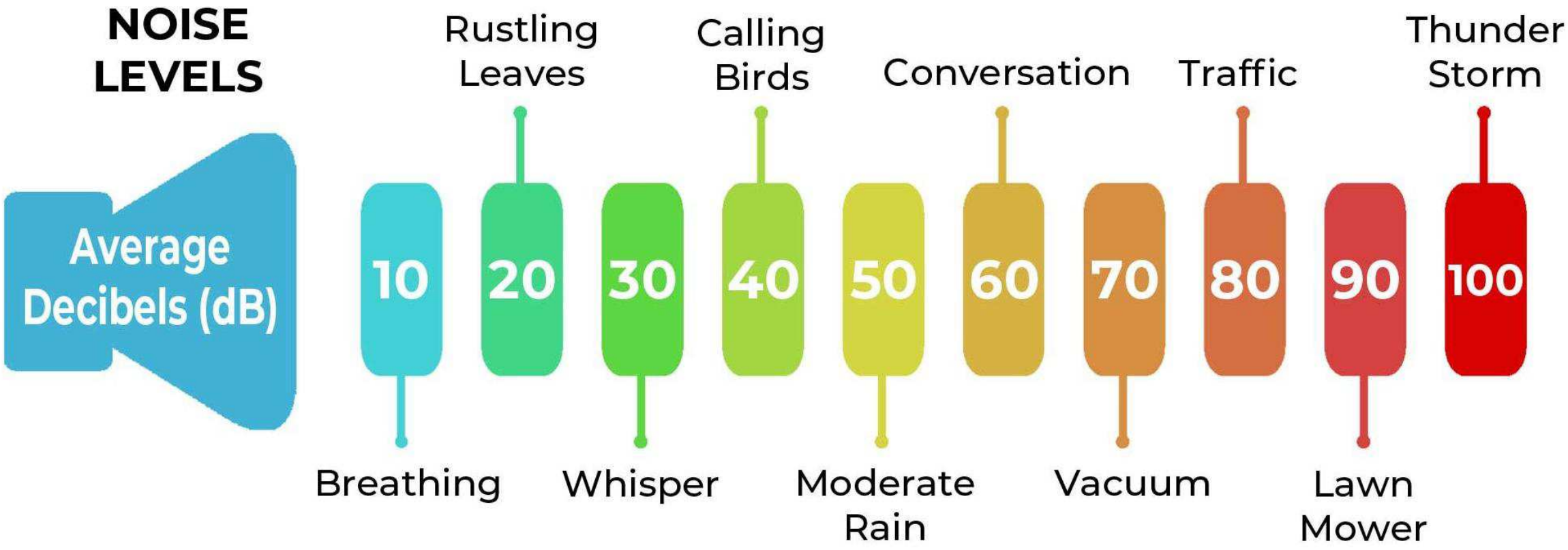
Measuring Noise

- Noise is determined by frequency and magnitude of sound waves
- Frequency:
  - Number of sound waves over time (Hz)
- Magnitude (dB)
  - A-weighted decibels dB(A)
  - C-weighted decibels dB(C)

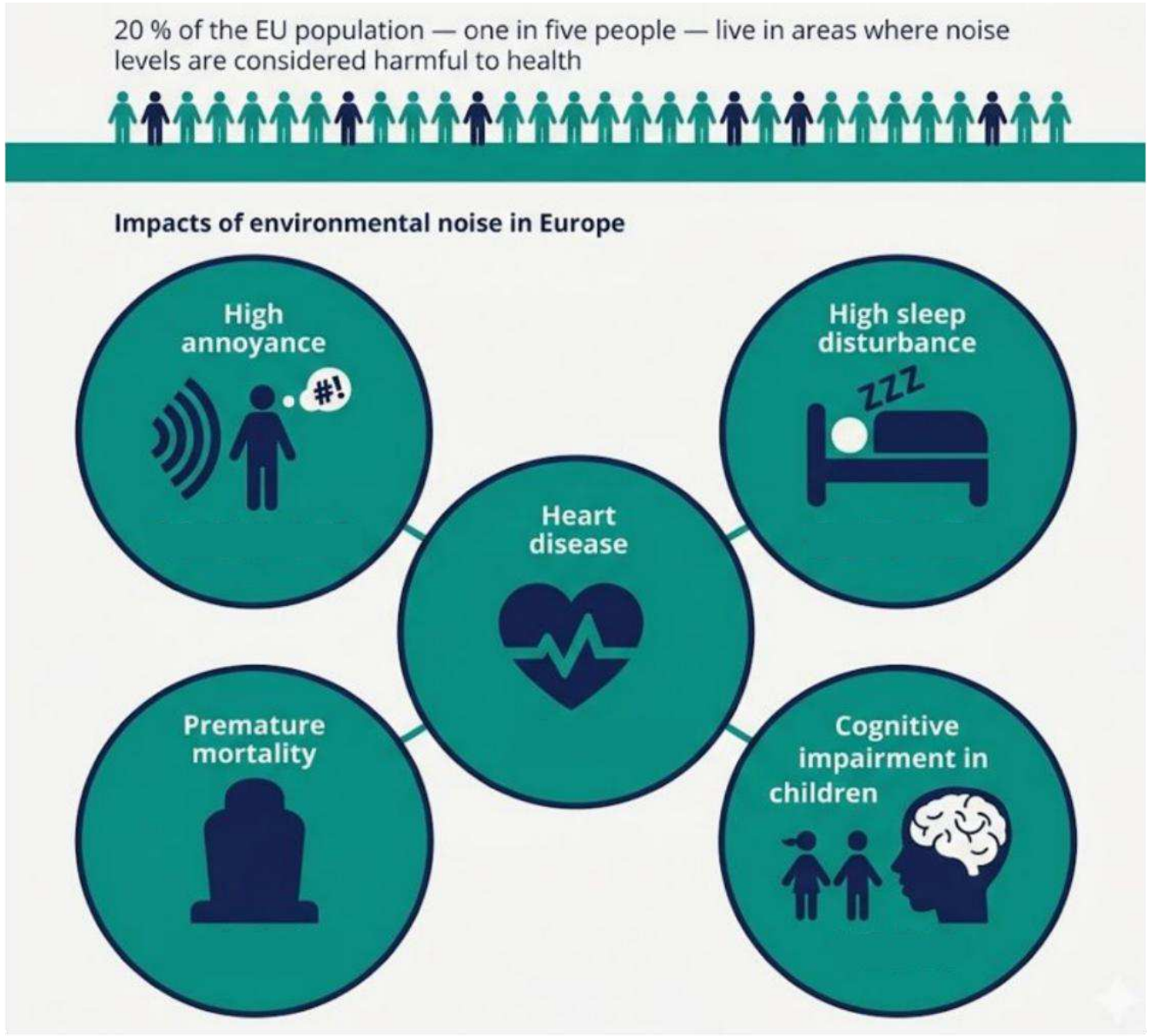


High and Low Frequency Waves (How Acoustic Foam Effects Sound Waves: Holland| SoundFix, n.d.)

Decibels



Blake, J. *Best Sound Level Meter (That Actually Records Data)*. Acoustic Nature. https://acousticnature.com/journal/best-sound-level-meter-for-recording (accessed 2026-02-26).



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Health Effects of Noise

- Constant state of alertness:
  - Increased cortisol
  - Low-quality sleep
  - Cardiovascular stress
- Increases risk:
  - Hypertension
  - Heart disease
  - Heart failure

https://www.eea.europa.eu/en/analysis/maps-and-charts/noise-pollution

Map of Inner City with neighborhoods.

Goal

Support Miljøpunkt Indre By & Christianshavn in evaluating whether current Danish noise measurement standards adequately account for problematic low-frequency environmental noise in the Inner City District of Copenhagen.

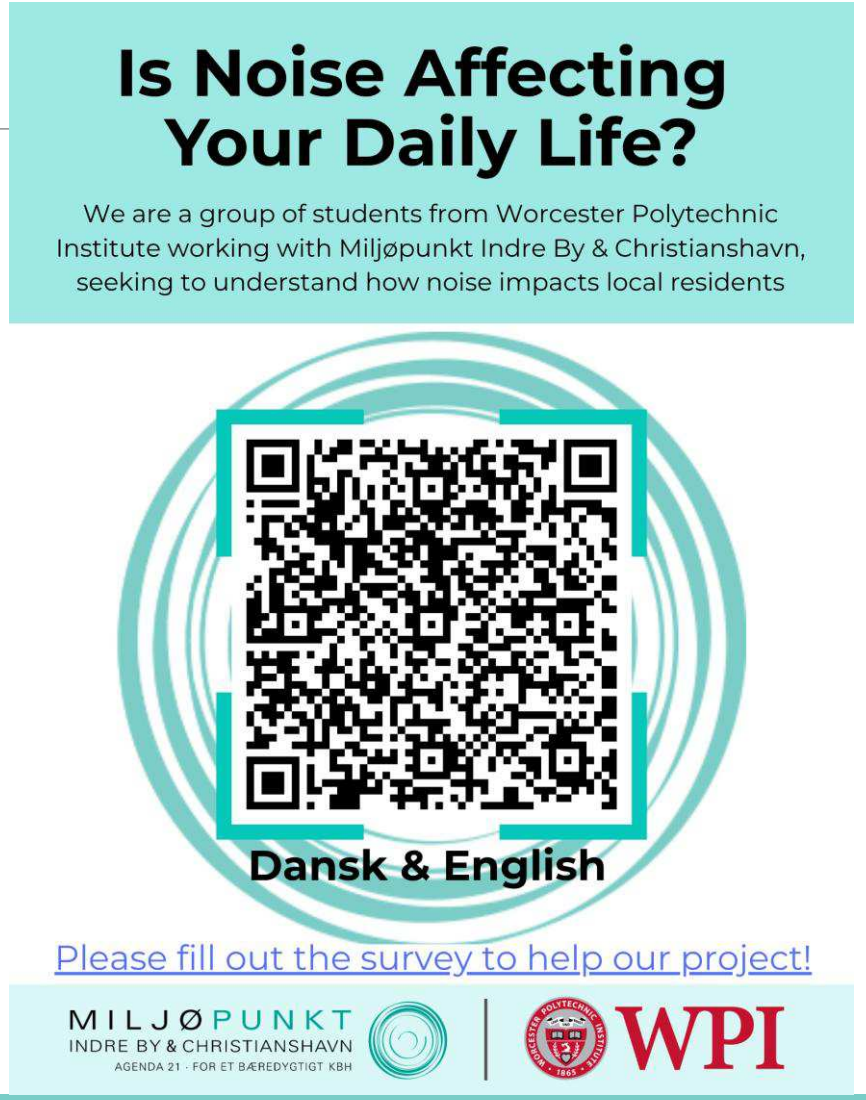
(*Bydelsplan | Indre By Lokaludvalg*, n.d.)

Main Results

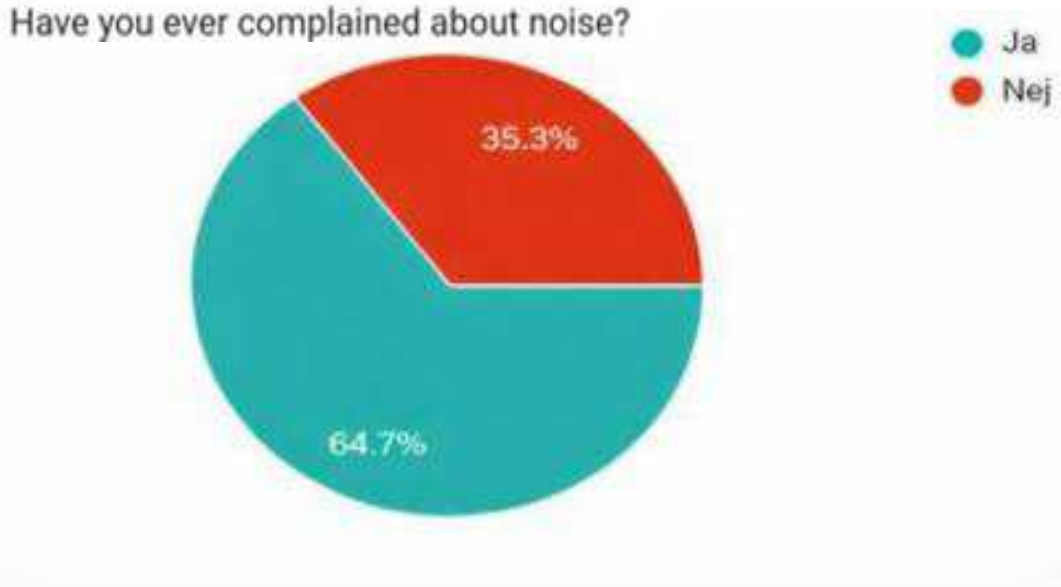
- Current standards and regulations are based around A-weighted noise
  - Does not fully encompass the “feeling” of low-frequency noise
- A single, identifiable noise source is needed to resolve a complaint
  - If the source is unknown or from multiple places, action cannot be taken
- Municipality often lacks jurisdiction to act on measurements
  - Outsource to noise measuring experts for fully accurate measurements and recommendations which can prolong the process

Survey Distribution

- Conducted outreach in public areas
- Shared survey through sponsor network
- QR codes on flyers/posters

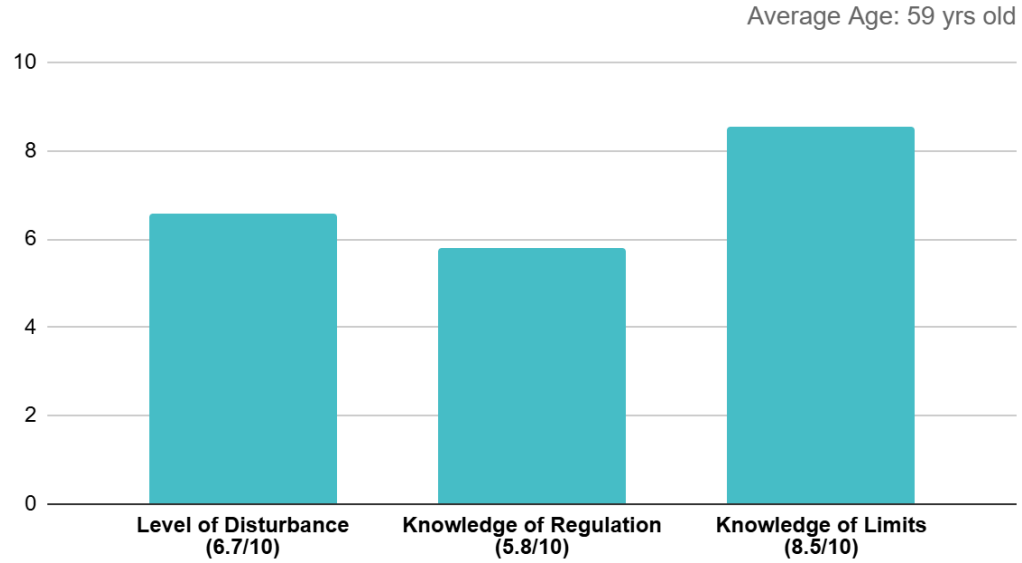


Survey Results



- **55%** of the individuals who complained about the noise received no help from the municipality

- Based on 18 residents' responses:
- Types of noise noticed the most: transportation, construction, music/nightlife



Conducting Interviews

Noise Experts

- Learn proper measurement techniques for LFN
- Identify what makes cooling and ventilation an issue

Municipality

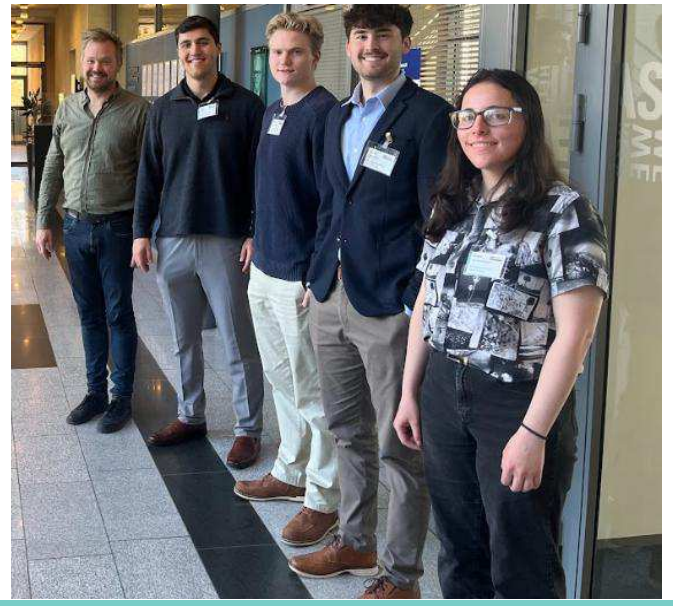
- Understand complaint response and measurement process
- Compare measurement process to expert advice

Public

- Hear experiences with cooling and ventilation annoyance
- Understand what happens when people make noise complaints

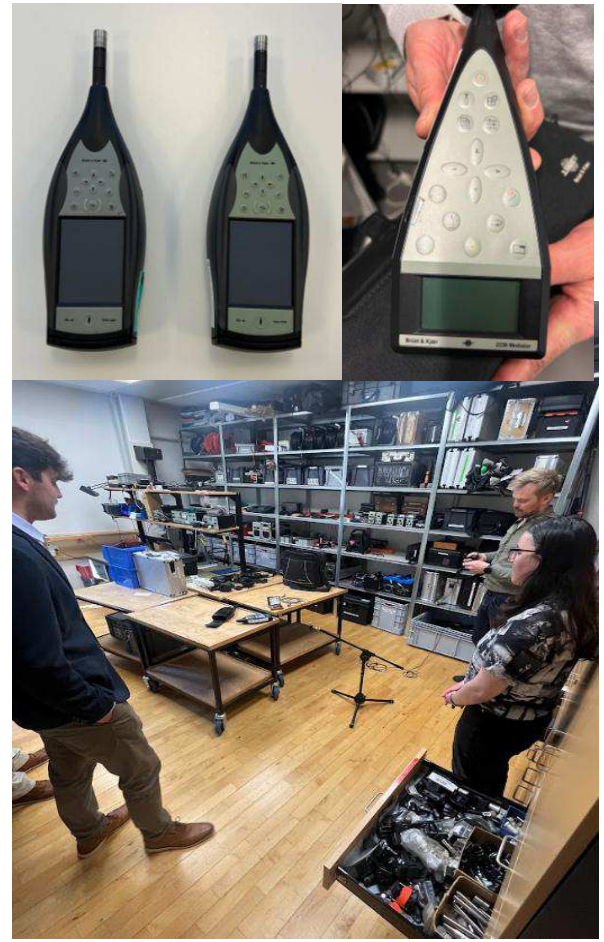
Regulatory Issues of Measuring Low-Frequency Noise

- Limited public awareness of noise standards
  - Especially for low-frequency noise
  - Misidentification of sources leads to dead-ends with Municipality
- Current regulations focus on A-weighted noise
  - Health studies focused on A-weighted noise
  - Would have to redo studies looking at C-weighted noise to justify a change



Technical Issues of Measuring Low-Frequency Noise

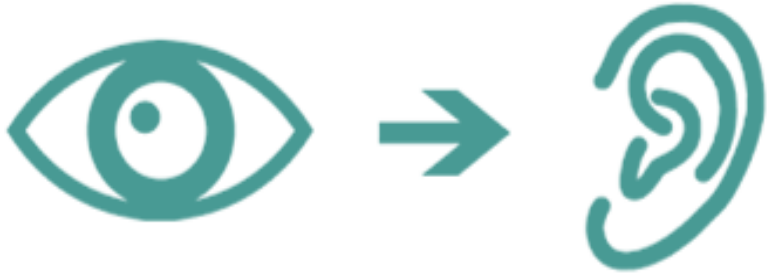
- Structural-borne vs. airborne noise
  - LFN primarily travels through vibrations through the building structure
  - Municipality does not measure structural-borne
  - Requires specific equipment to collect properly
- Combined noise sources can exceed limits despite individual compliance



Psychological Aspect of Noise

Noise Pollution

- Sources of noise can be more annoying if you see them as well as hear them

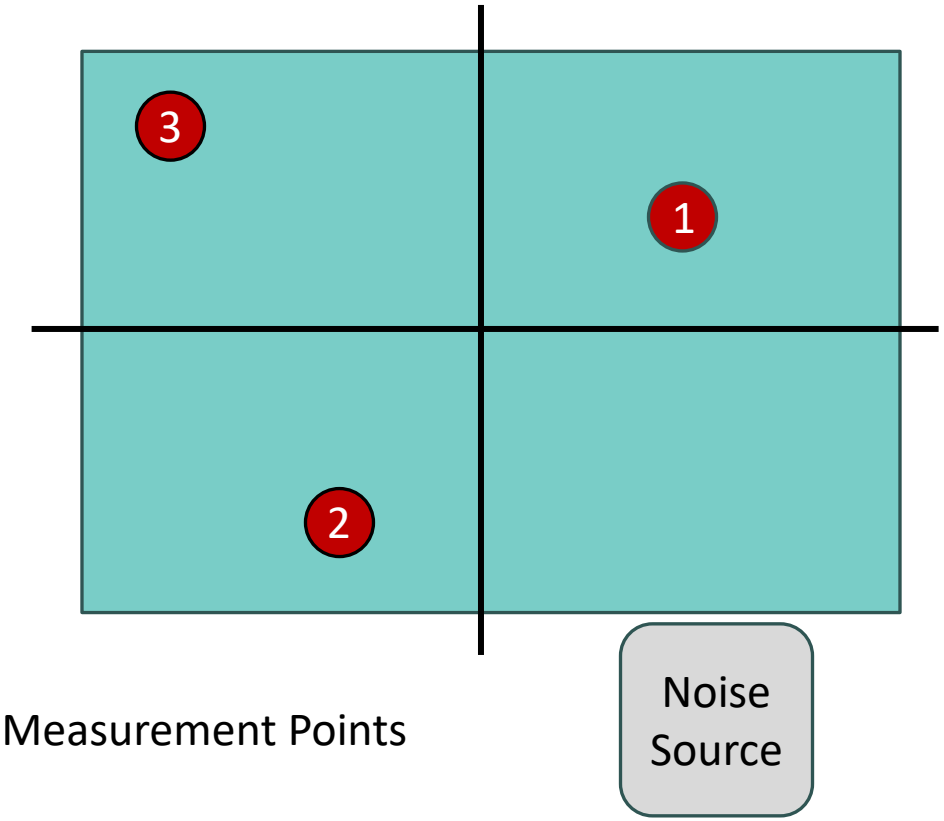


Measuring Noise Pollution

- Just having someone listen to complaints can be beneficial
- Even just measuring the source can be enough even if it leads to nothing being done

Measurement Process

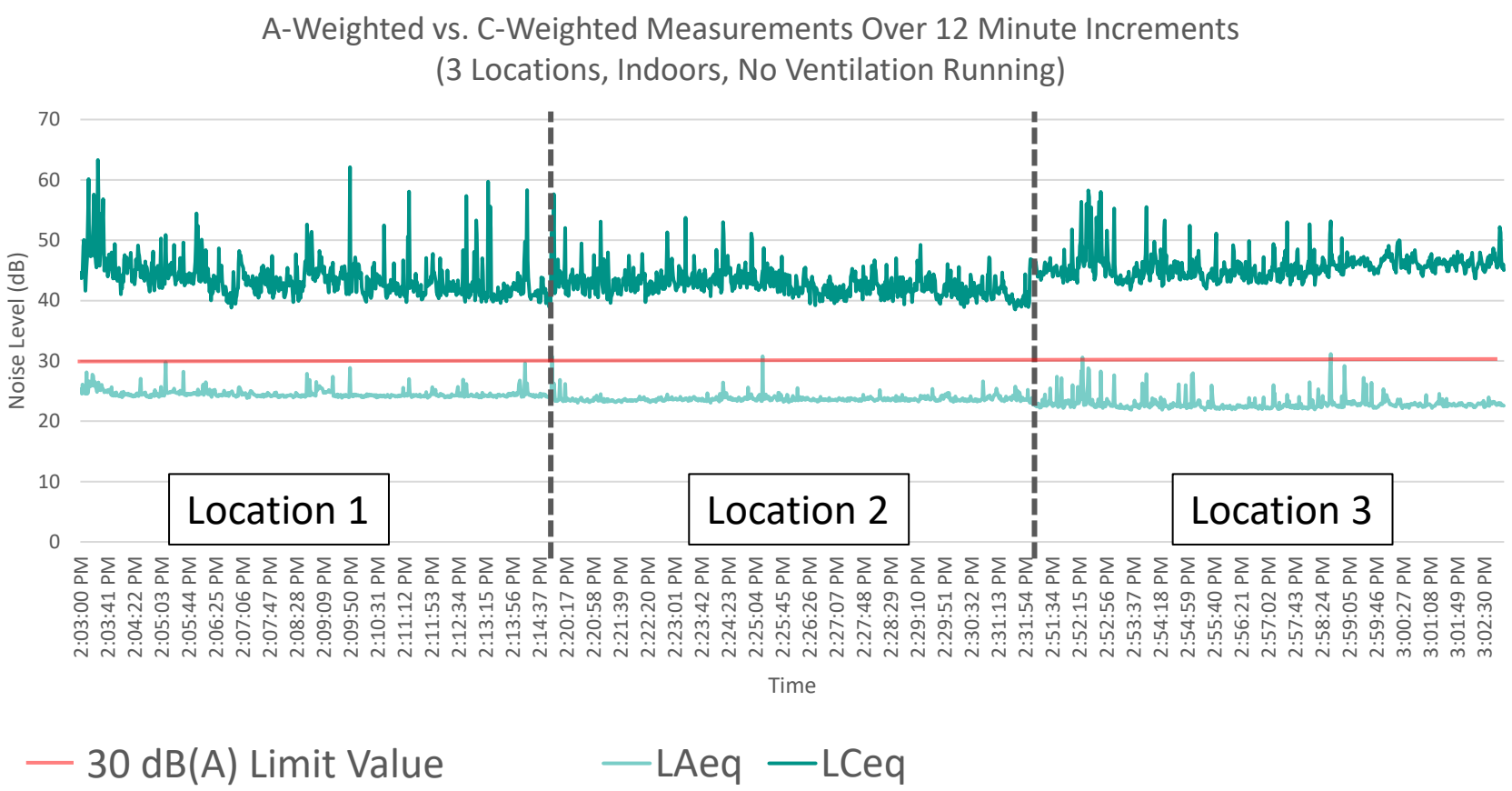
Example Measuring Setup



Danish Environmental Protection Agency Guidance No. 9/1997:

- Background control noise measurement
- Three different measurement points
  - Away from the center of the room, walls, floor, and ceiling
- Constant noise: 10-20 minutes
- Intermittent noise: All day/overnight

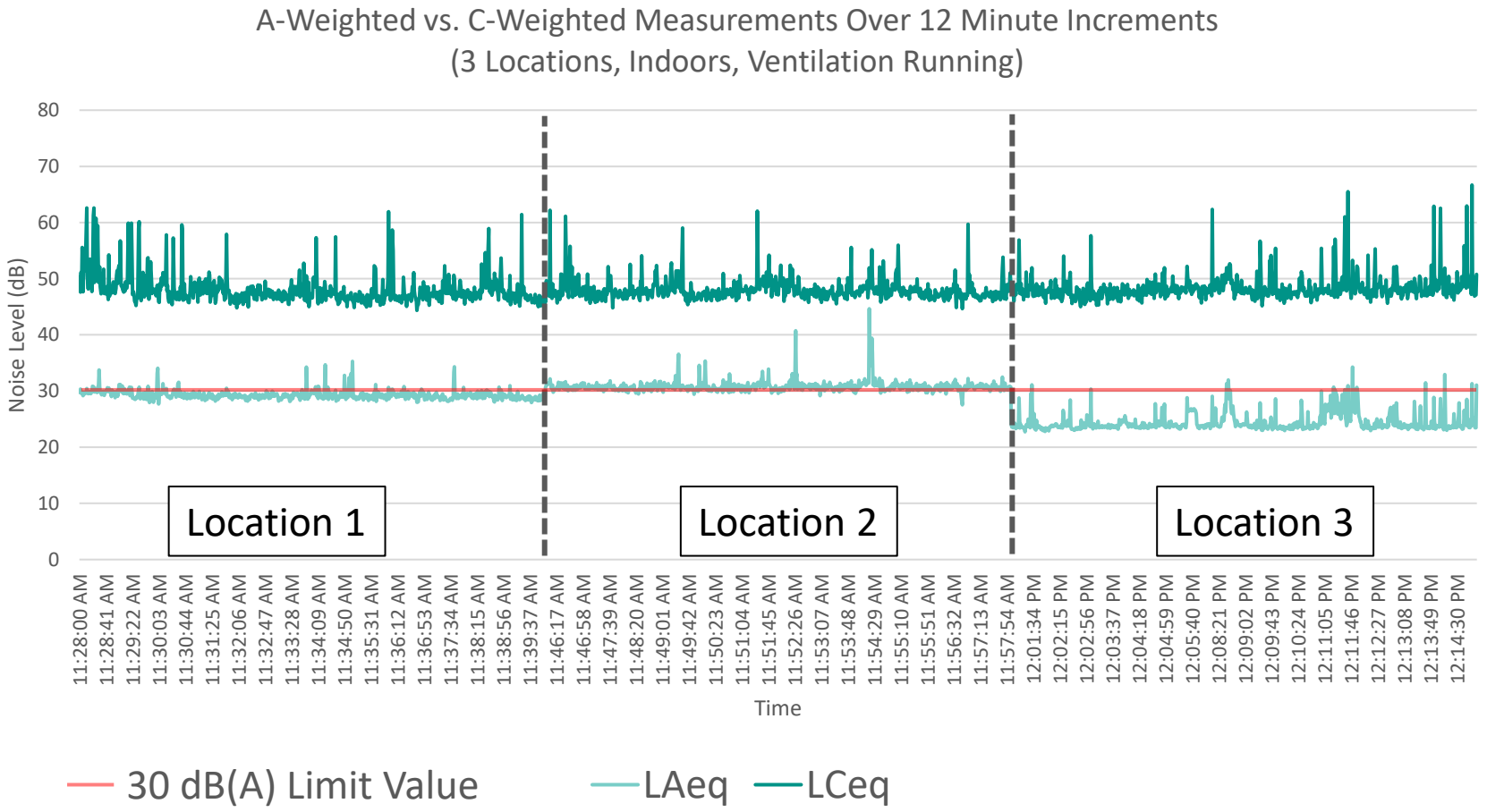
Measurement Results



	Noise Level (dB)
Average C-Weighted	44.052
Average A-Weighted	23.716

Location	Time Period	Limit Value
Living room	07:00–22:00	30 dB(A)
Living room	22:00–07:00	25 dB(A)
Living room	Night (max level)	40 dB(A)
Office premises	All day	40 dB(A)

Limit values for building-transmitted noise measured indoors in living spaces/office spaces, from "Cooling and ventilation regulations in Copenhagen, Appendix 2."



	Noise Level (dB)
Average C-Weighted	48.122
Average A-Weighted	28.187

Location	Time Period	Limit Value
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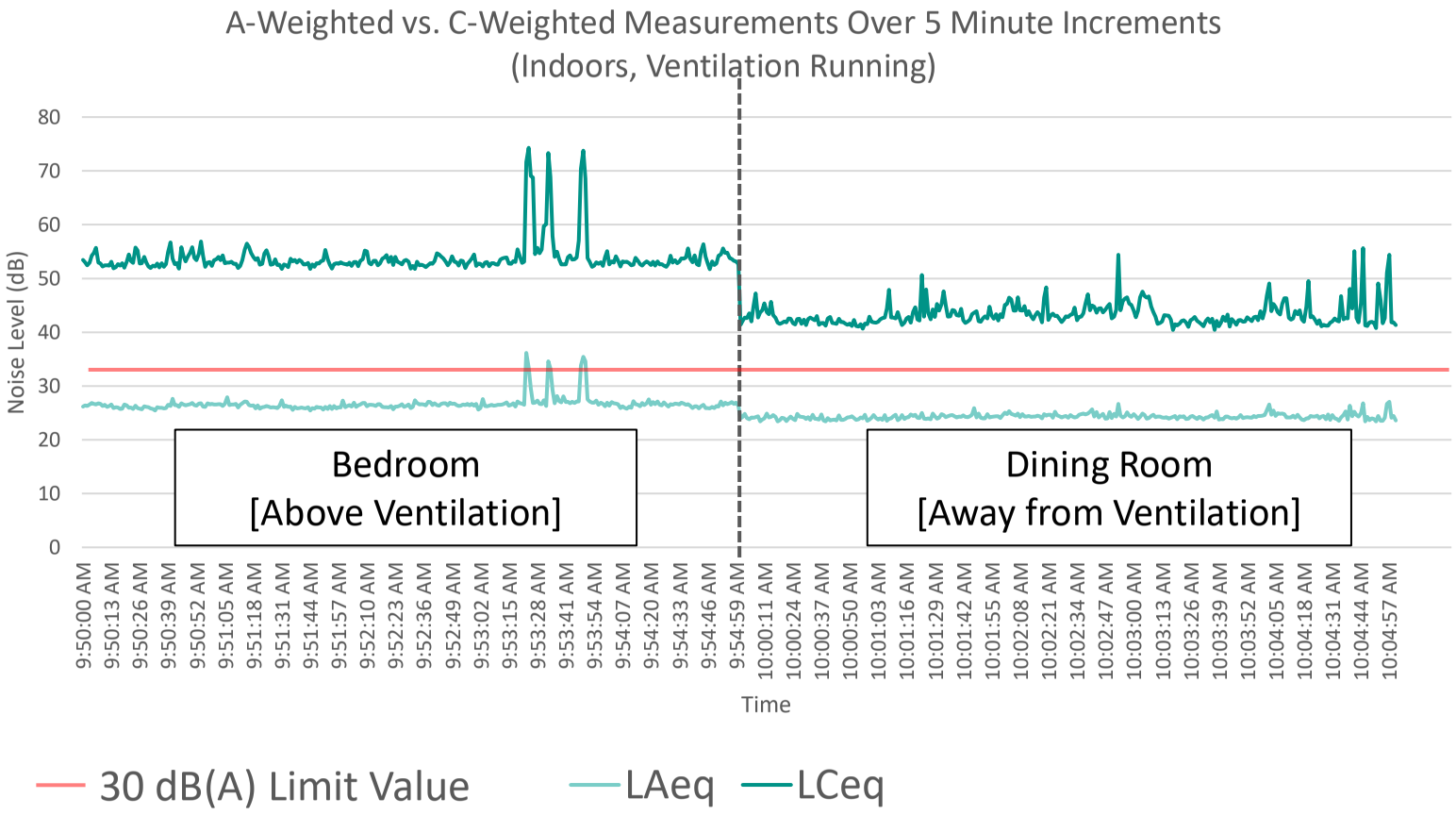
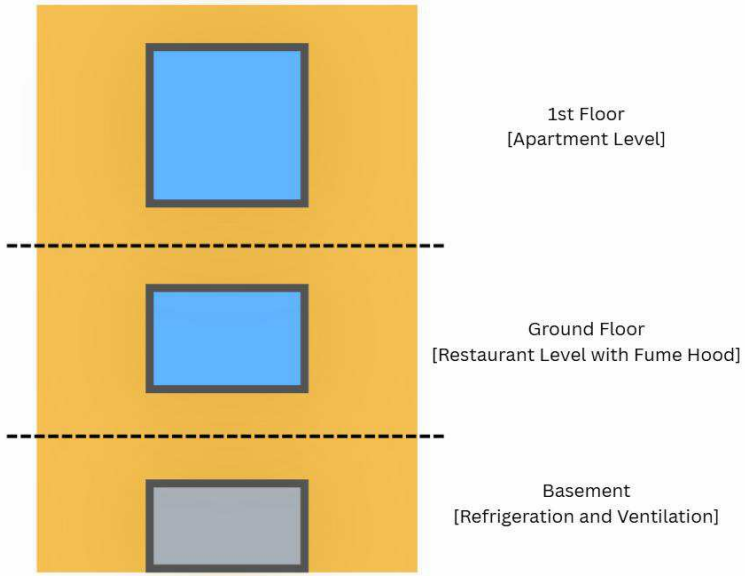
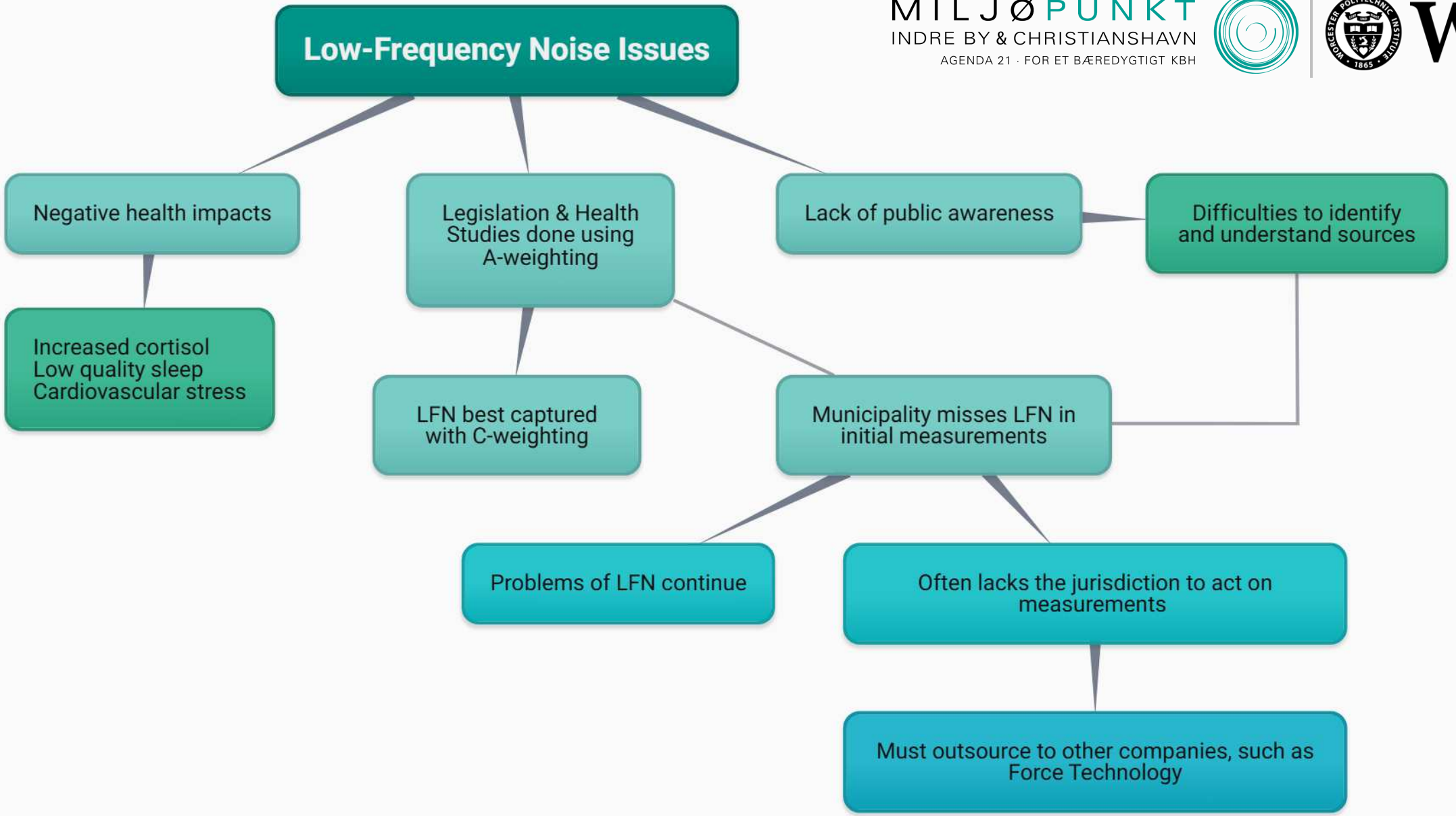


	Noise Level (dB)
Average Bedroom C-Weighted	53.876
Average Dining Room C-Weighted	43.350
Average Bedroom A-Weighted	26.655
Average Dining Room A-Weighted	24.322




Low-Frequency Noise Issues
Negative health impacts
Increased cortisol
Low quality sleep
Cardiovascular stress
Legislation & Health Studies done using A-weighting
LFN best captured with C-weighting
Lack of public awareness
Difficulties to identify and understand sources
Municipality misses LFN in initial measurements
Problems of LFN continue
Often lacks the jurisdiction to act on measurements
Must outsource to other companies, such as Force Technology

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Thank you for your time!

Questions?

Please fill out our survey on the public opinion on noise pollution

H Final Project Presentation

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WPI

Evaluating Noise Pollution and Health Impacts from Cooling and Ventilation Systems

By Ally Wiesendanger [ME], Connor Piper [AREN], Jensen Gilbert [AE], and Nicholas DeBrito [ME]

April 30th, 2026

Miljøpunkt Indre By & Christianshavn

- Improve quality of life
- Increase sustainability in the Inner City
- Influence legislation
- Three focus areas:
  - **Healthy City**
  - Green City
  - Circular City

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Urban Noise Sources

Main Cooling and Ventilation Sources

Traffic

Construction

Social

Restaurants
Cafés
Events

Industrial

Neighborhood

Cooling and Ventilation Noise Pollution

Cooling and Ventilation Systems operate continuously

Primary Sources

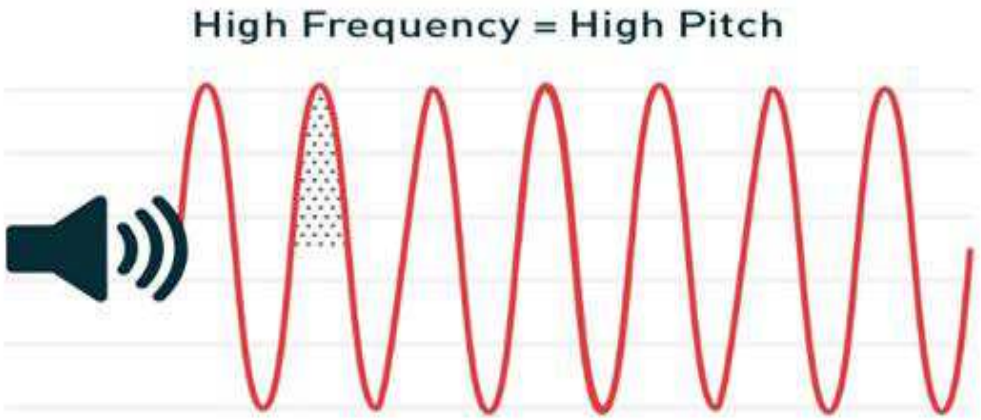
- Fans, compressors, motors
- Airflow in ducts

Spreads Through Nearby Structures

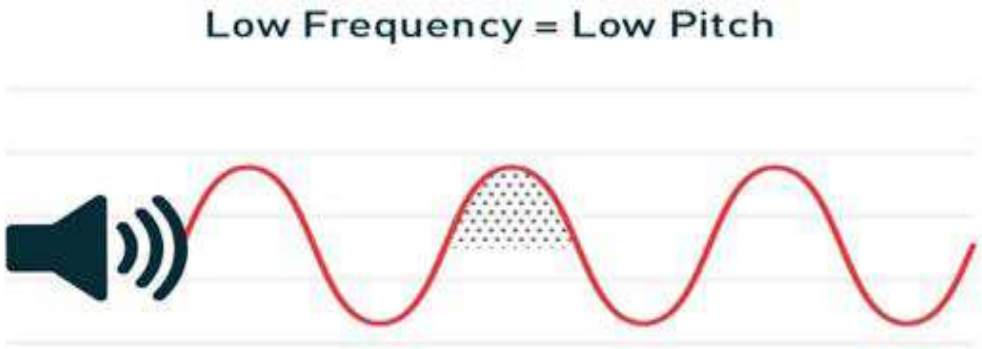
- Sounds propagate via vibration

Measuring Noise

- Noise is determined by frequency and magnitude of sound waves
- Frequency:
  - Number of sound waves over time (Hz)
- Magnitude (dB)
  - A-weighted decibels dB(A)
  - C-weighted decibels dB(C)



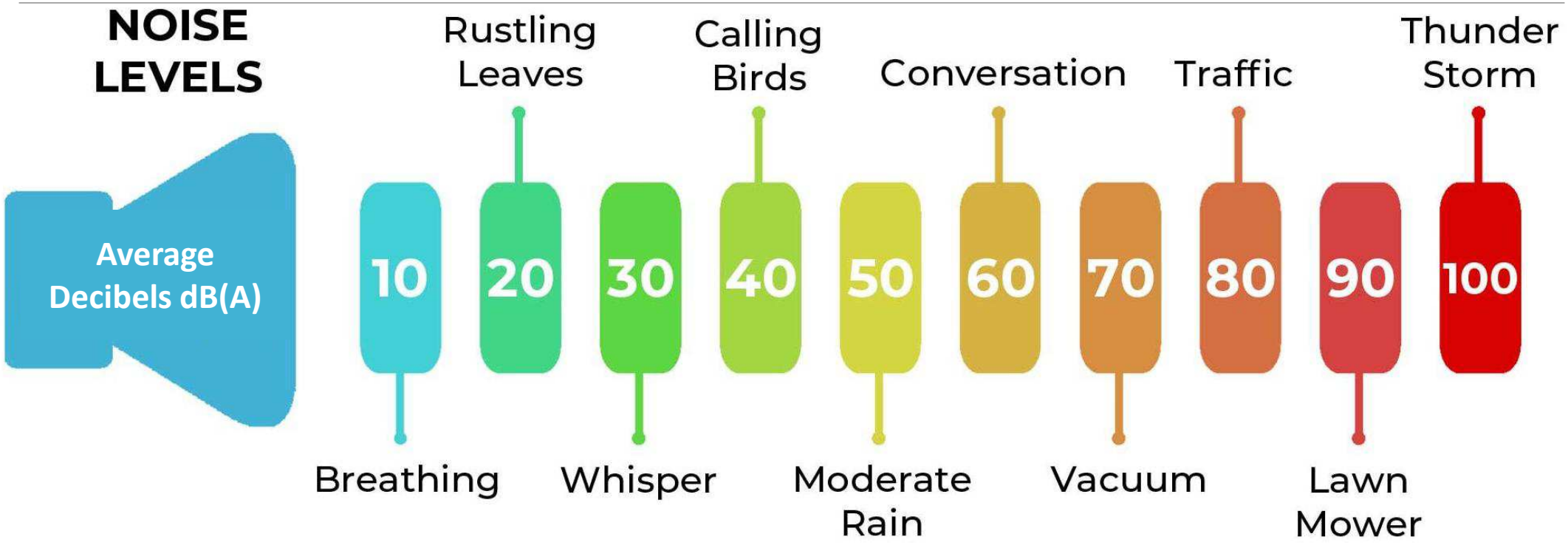
8KHz-20KHz (dB(A))



30Hz-8KHz (dB(C))

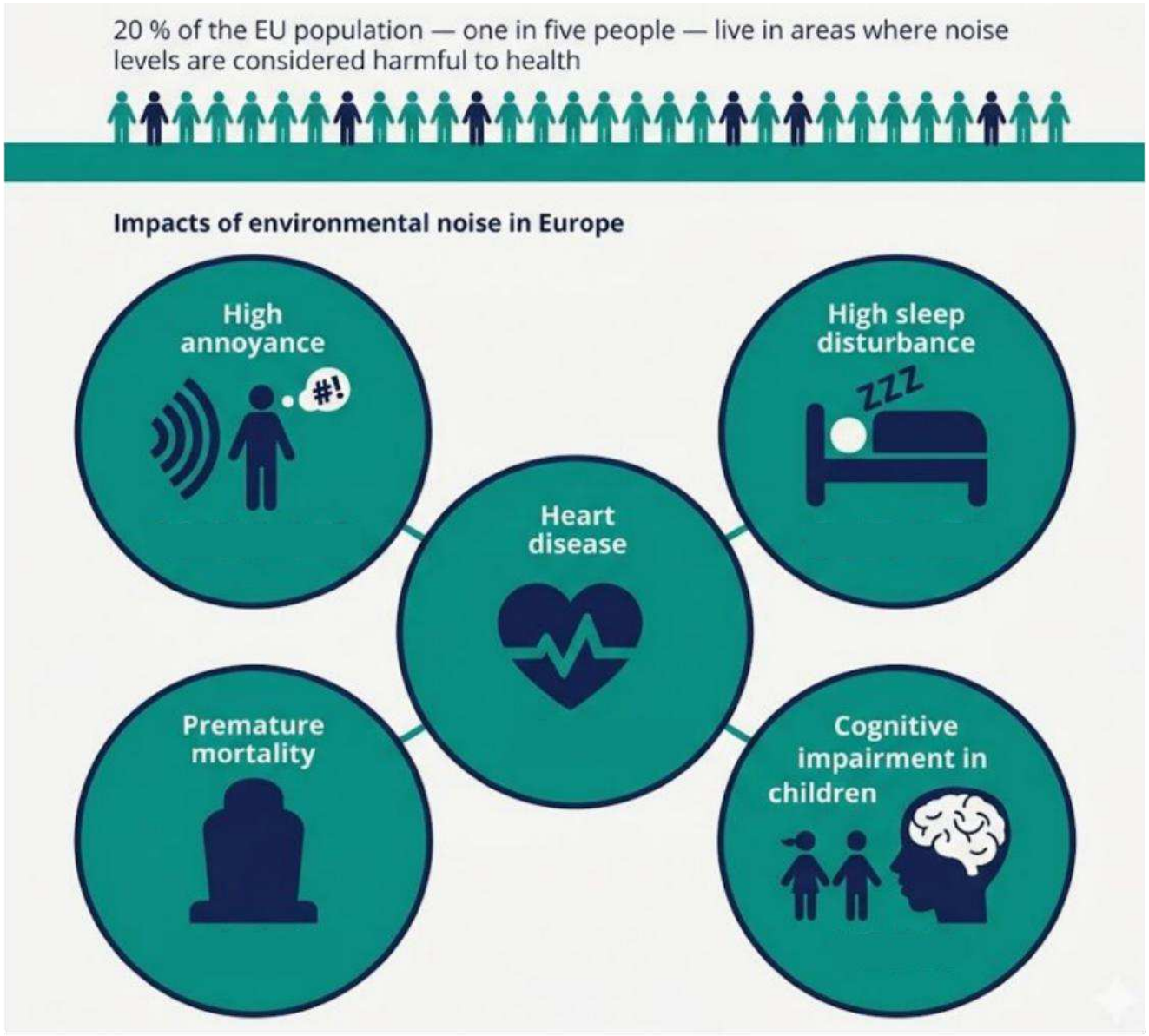
High and Low Frequency Waves (How Acoustic Foam Effects Sound Waves: Holland| SoundFix, n.d.)

Perceived Loudness - dB(A) vs dB(C)



SOUND SOURCE	DBA (WHAT YOU HEAR)	DBC (ACTUAL ENERGY)	DIFFERENCE
Vacuum Cleaner	70 dBA	75 dBC	Moderate (~5 dB)

Blake, J. *Best Sound Level Meter (That Actually Records Data)*. Acoustic Nature. https://acousticnature.com/journal/best-sound-level-meter-for-recording
Ray, M. (2026, March 9). *dBA vs dBC: Which One Should You Use?* https://realtimesoundmeter.org/blog/dba-vs-dbc



Health Effects of Noise

- Constant state of alertness:
  - Increased cortisol
  - Low-quality sleep
  - Cardiovascular stress
- Increased risk of:
  - Hypertension
  - Heart disease
  - Heart failure

European Environmental Agency. (2020, October 15). *Noise pollution*. https://www.eea.europa.eu/en/analysis/maps-and-charts/noise-pollution

Map of Inner City with neighborhoods.

Goal

Support Miljøpunkt Indre By & Christianshavn in evaluating whether current Danish noise measurement standards adequately account for problematic low-frequency environmental noise in the Inner City district of Copenhagen.

Bydelsplan | Indre By Lokaludvalg. (n.d.) https://indrebylokaludvalg.kk.dk/om-lokaludvalget/lokaludvalgets-arbejde/bydelsplan

Objectives

Objective 1: Assess Opinions

- Talk to residents, the municipality, and noise experts
- Ask about opinions on noise and legislation

Objective 2: Measure and Analyze

- Measure cooling and ventilation systems
- Compare to public annoyance

Objective 3: Present Findings and Educate

- Present to Inner City Local Committee
- Add materials to the sponsor's website

Main Results

- **Current standards and regulations are based on A-weighted noise**
  - Does not fully encompass the “feeling” of low-frequency noise
- **A single, identifiable noise source is needed to resolve a complaint**
  - If the source is unknown or from multiple places, action cannot be taken
- **Municipality may have limited authority to act directly on certain measurements**
  - Detailed noise assessments by external experts may be needed to ensure accuracy, which can extend the overall complaint process

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Objective 1:

Survey Distribution & Interviews

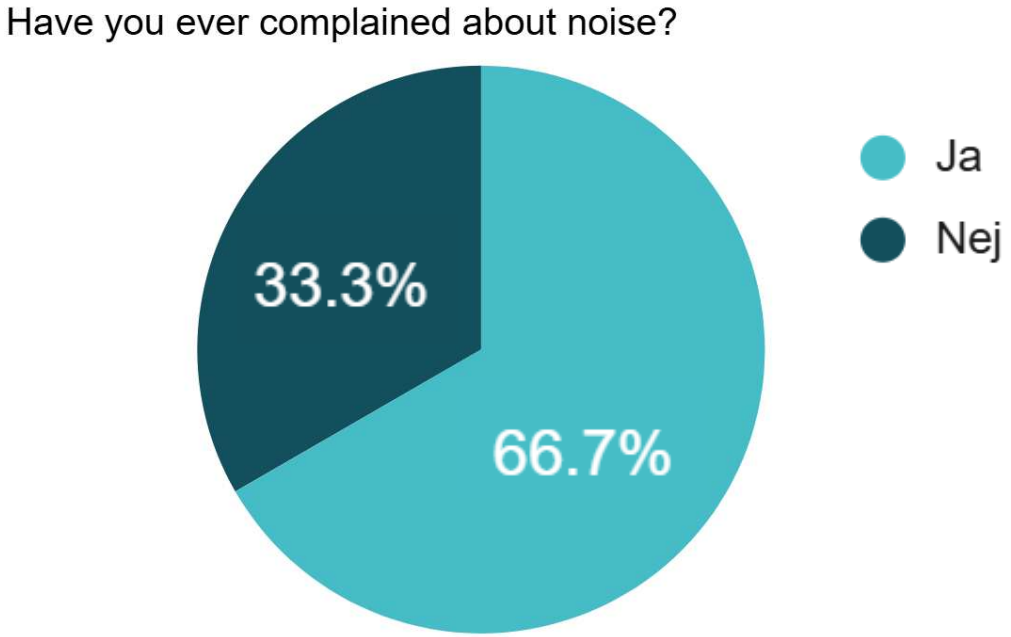
Survey Distribution

- Public Outreach
- Sponsor Network
- Flyers/Posters

Conducting Interviews

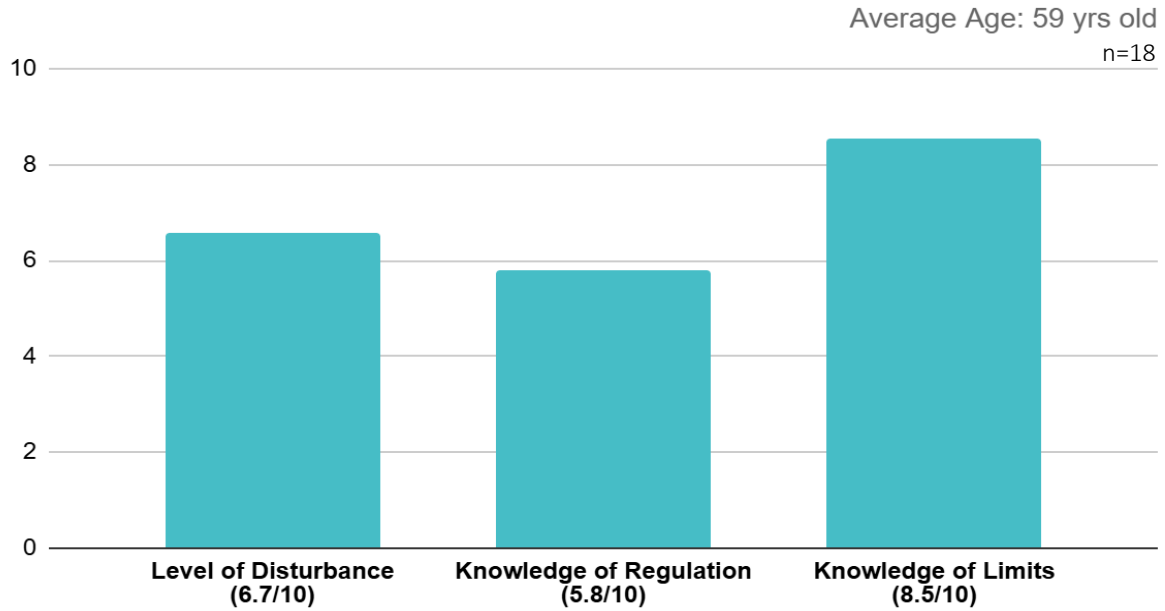
- Noise Experts
- Municipality
- Public

Objective 1:
Survey Results



- **55%** of the individuals who complained about the noise received no help from the municipality

- Based on **18** residents' responses:
- Types of noise noticed the most: transportation, construction, music/nightlife



Objective 1:
Regulatory Issues of Measuring Low-Frequency Noise

- Limited public awareness of noise standards
  - Especially for low-frequency noise
  - Misidentification of sources leads to dead ends with the Municipality
- Current regulations focus on A-weighted noise
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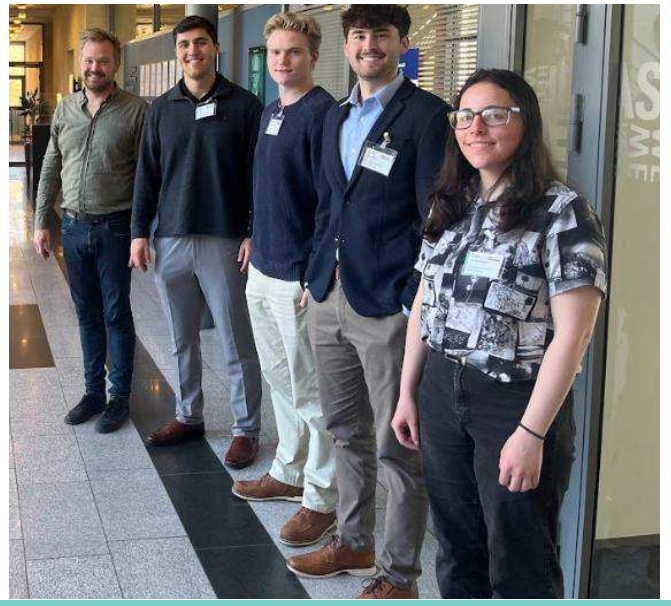
  - Redo studies using C-weighted noise to justify a change



Objective 1:
Technical Issues of Measuring Low-Frequency Noise

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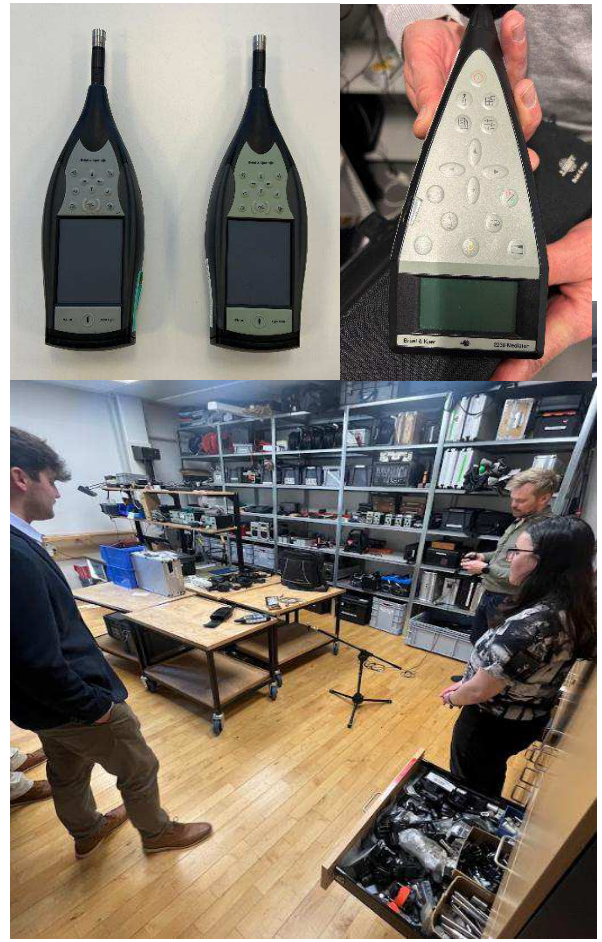
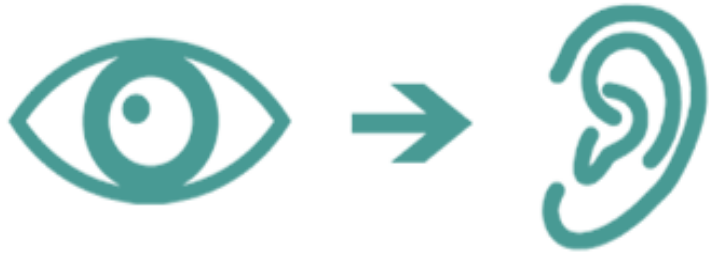
- Structural-borne vs. airborne noise
  - LFN primarily travels through vibrations through the building structure
  - Municipality does not measure structural-borne
  - Requires specific equipment to collect properly
- Combined noise sources can exceed limits despite individual compliance



Objective 1:
Psychological Aspect of Noise

Noise Pollution

- Sources of noise can be more annoying if you see them as well as hear them

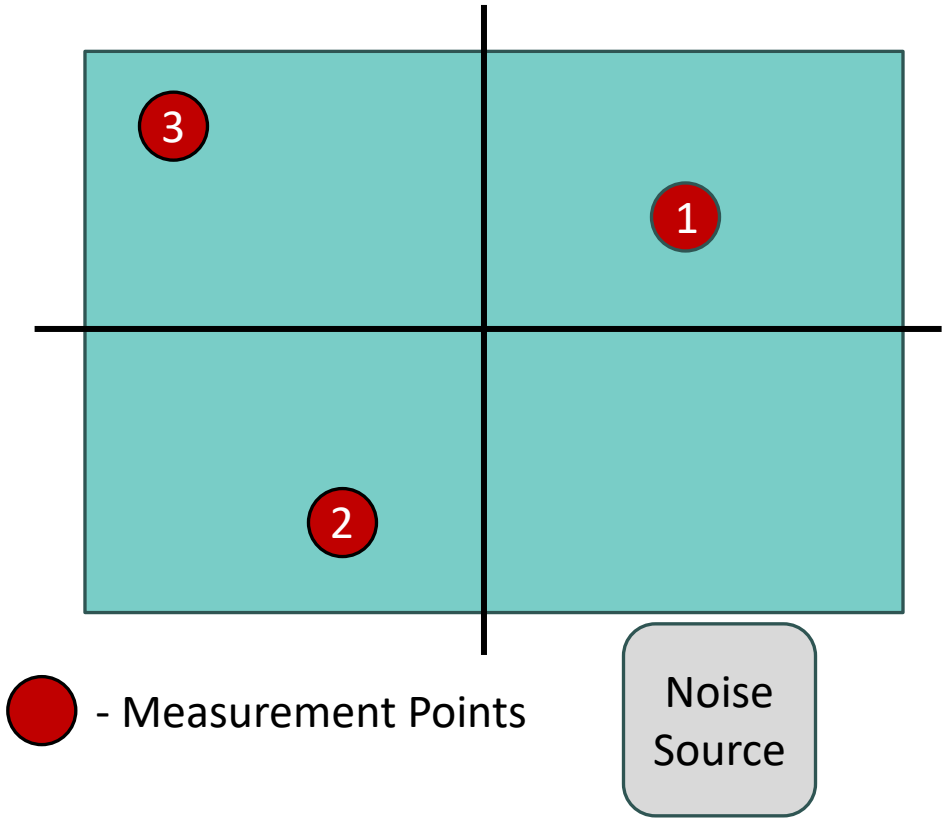


Measuring Noise Pollution

- Just having someone listen to complaints can be beneficial
- Even just measuring the source can be enough even if it leads to nothing being done

Objective 2:
Measurement Process

Example Measuring Setup



Danish Environmental Protection Agency Guidance No. 9/1997:

- Three different measurement points
  - Away from the center of the room, walls, floor, ceiling, and other measurement points
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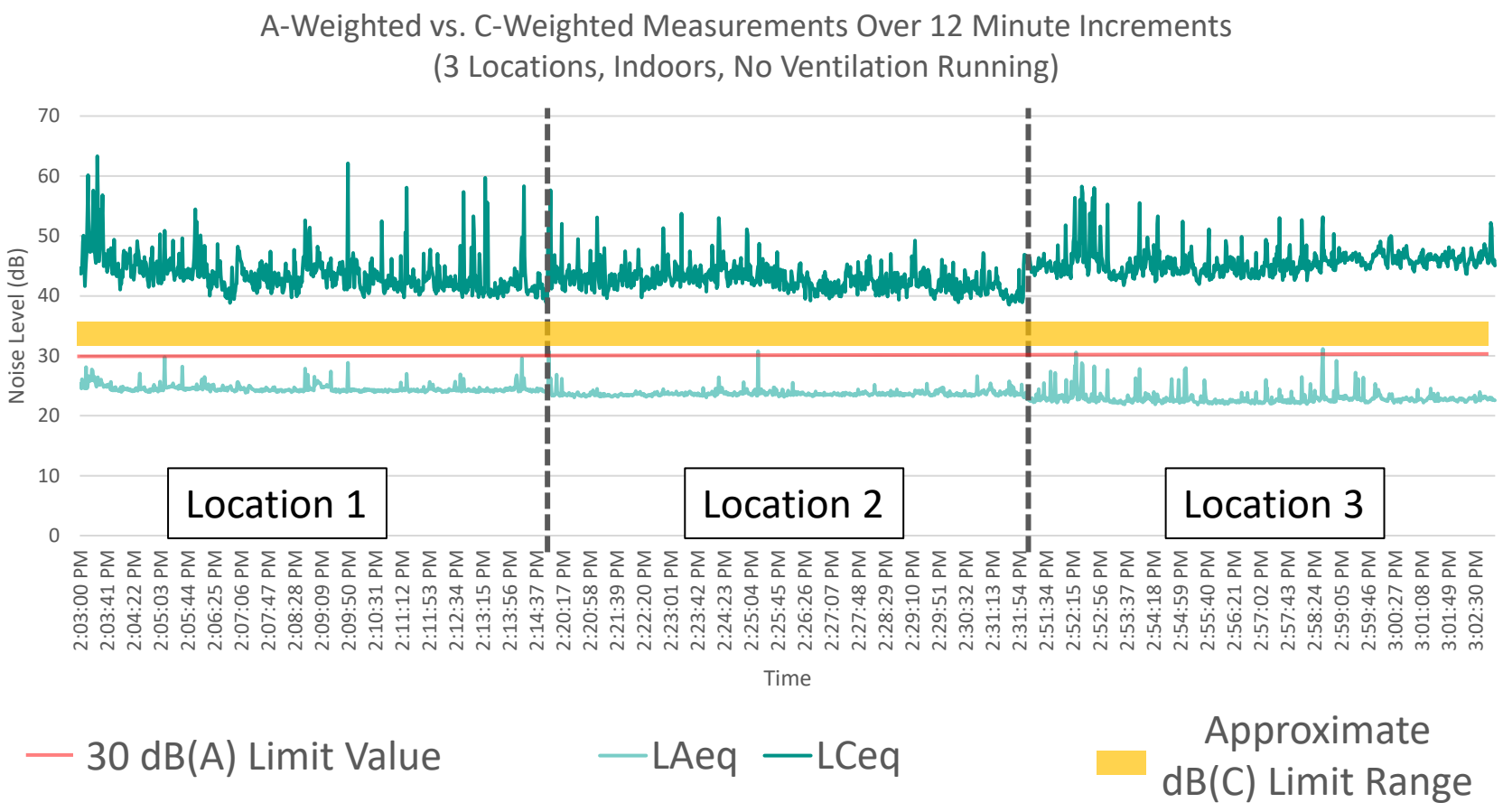
Objective 2:
Measurement Results – Office Kitchen



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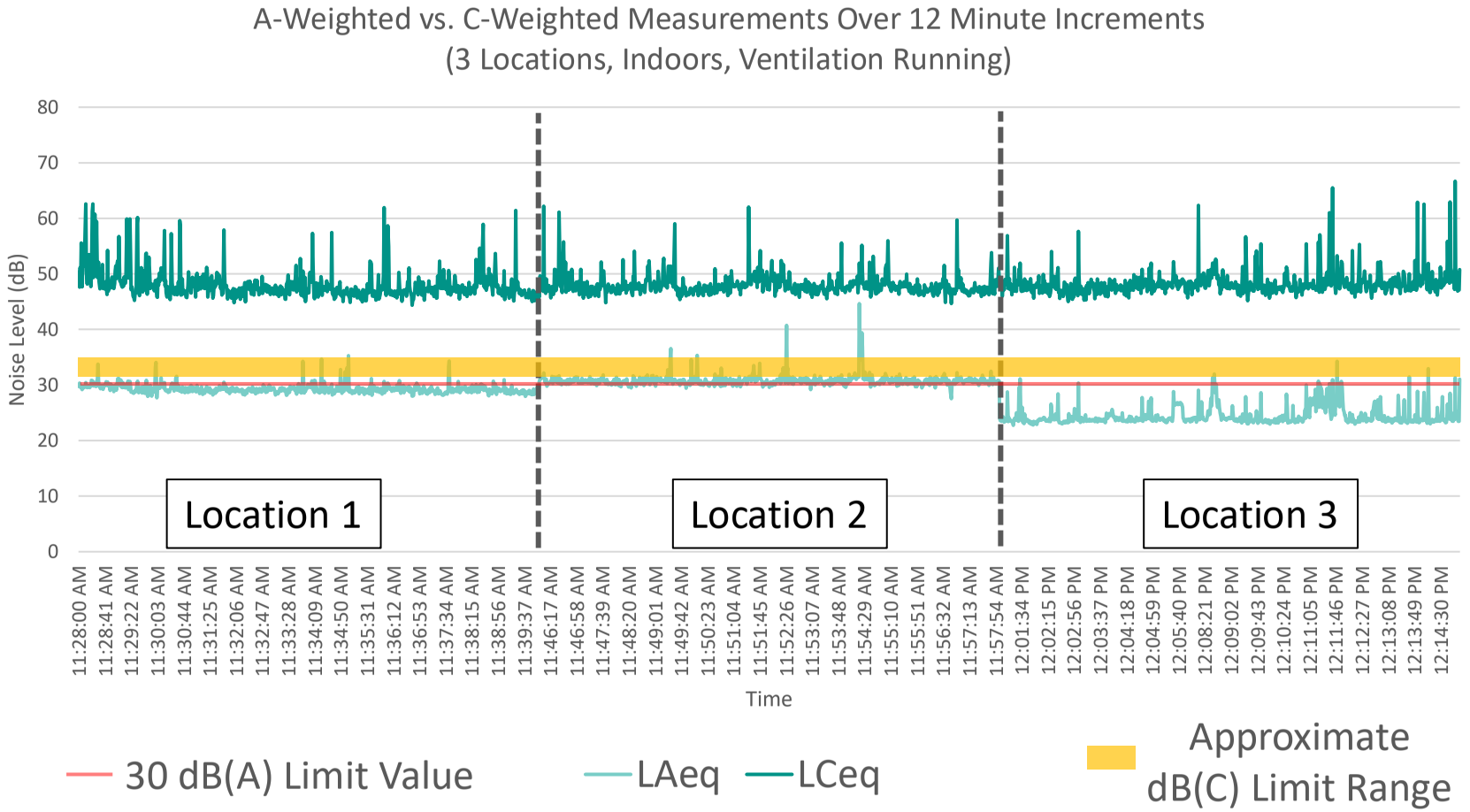
Measurement Results – Office Kitchen

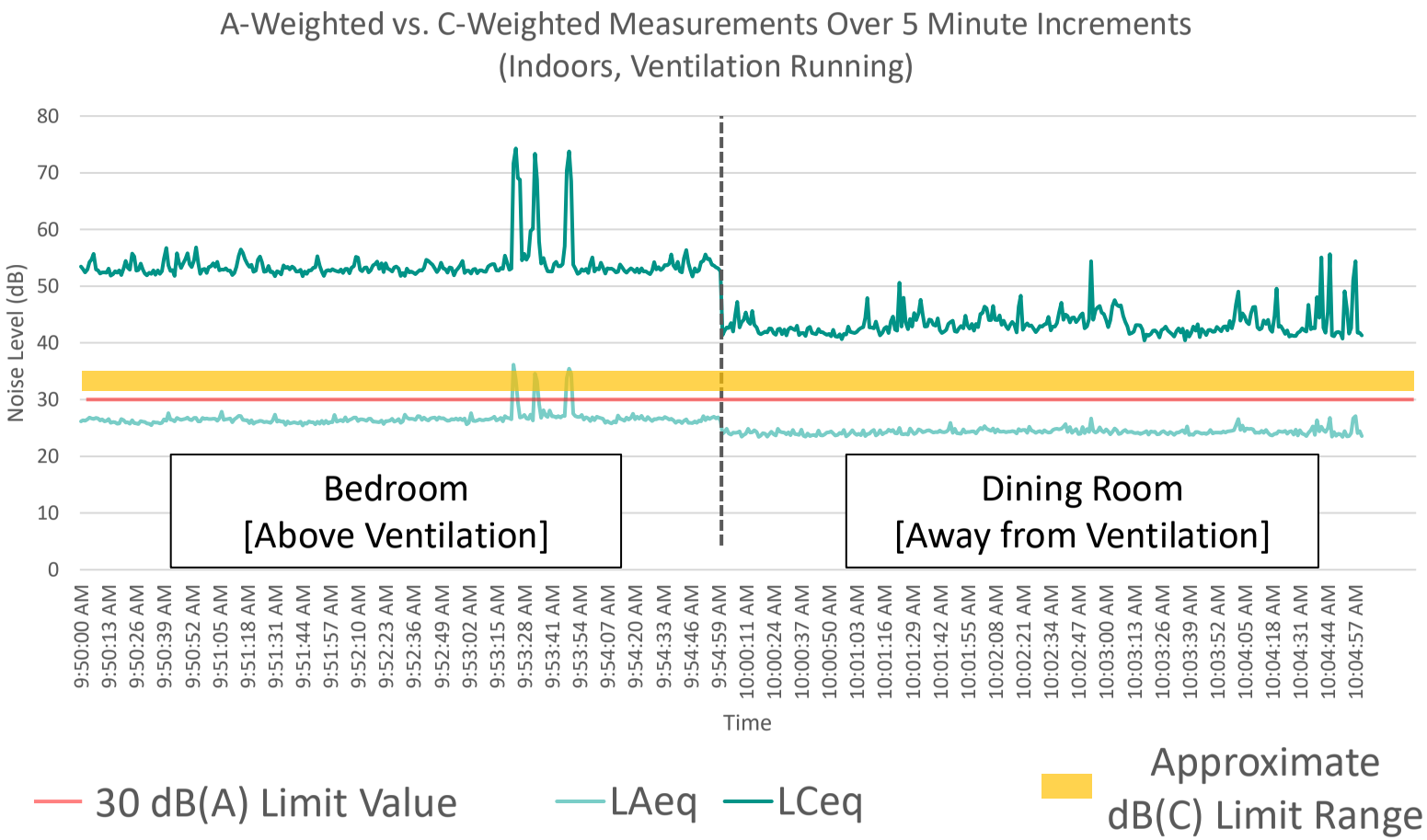


No Ventilation Running	
	Noise Level (dB)
Average C-Weighted	44.052
Average A-Weighted	23.716

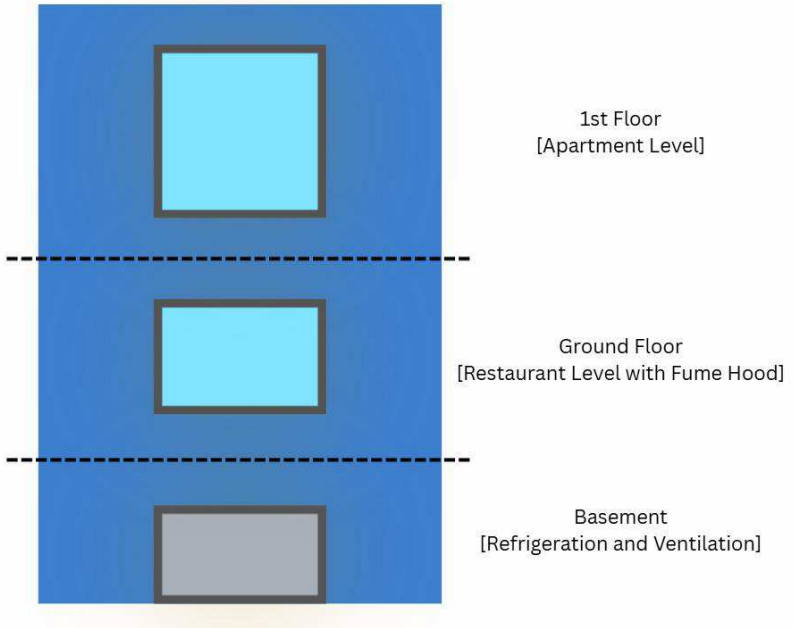
Ventilation Running	
	Noise Level (dB)
Average C-Weighted	48.122
Average A-Weighted	28.187

Overall Change	
	Noise Level (dB)
Average C-Weighted	4.070
Average A-Weighted	4.471

Objective 2:
Measurement Results – Survey Respondent



	Noise Level (dB)
Average Bedroom C-Weighted	53.876
Average Dining Room C-Weighted	43.350
Average Bedroom A-Weighted	26.655
Average Dining Room A-Weighted	24.322



Objective 3:
Committee Presentation & Sponsor's Website

- Committee Presentation
  - Presented findings to stakeholders in the community
  - Requested recommendations on next steps in the project cycle
  - Particularly interested in the health aspect of noise
- Compiled findings on sponsor's website
  - Includes report, presentations, data, and audio recordings for reference

Recommendations:

Legislative Changes & Public Awareness

Legislative:	National Health Law (2027) Include LFN & compounding noise
Municipality:	Measure with C-weighting Data collection
Public:	Learn about health risks Define and identify LFN
Businesses:	Proper installation and maintenance Understand their systems' impact

Low-Frequency Noise Summary

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Low-Frequency Noise Issues

- **Health Impacts**
  - Increased cortisol, depression, anxiety, and heart problems
  - Lower quality sleep
- **Technical Issues of Measuring LFN**
  - LFN is primarily structural borne
  - LFN is better captured with C-weighting
- **Compounding Noise**
  - Multiple sources in the legal limit combine over the regulations
- **Current Legislation and Health Studies**
  - Done in A-weighting
  - Would need to be redone with C-weighting
- **Public's Perspective**
  - Difficult in identifying and describing LFN sources

Municipality does not fully capture low-frequency noise in initial measurements

Thank you for your time!

Questions?

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