Balancing Speech Privacy and Embodied Carbon Reduction in Building Design

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Abstract - Appropriate speech privacy between two spaces depends not only on partition sound insulation but also on background noise levels within the receiving room. While high sound insulation requirements can escalate construction costs and increase the embodied carbon footprint of acoustic designs, sound masking may provide a unique solution. By elevating background noise, sound masking achieves comparable acoustic privacy while reducing the need for high-insulation materials. Beyond carbon reduction, sound masking can also present advantages in achieving a more robust speech privacy outcome. This paper explores the benefits of sound masking as a possible tool in enabling a low carbon design as well as its potential for more robust speech privacy outcome.

1 INTRODUCTION

Acoustic performance in buildings is essential for occupant wellbeing and productivity. Poor acoustics is one of the biggest sources of dissatisfaction in office spaces. One study carried out by Haapakangas et al. (2008) indicate that about 50% of open office occupants and 20 % of occupants in private rooms were found to be dissatisfied with acoustics being the major reason Other studies suggest similar conclusions with respect to impact of space acoustics with aspects such as difficulty in concentration, tiredness, cognitive and critical thinking performance affected (Haapakangas, Helenius, Keskinen, & Hongisto, 2008) (Liebl, et al., 2012).

Ambient noise level is amongst one of the most frequent sources of disturbance in office environments in particular in open plan settings and where background speech is present. (Liebl, et al., 2012). High noise exposure and background speech of high intelligibility has been attributed to reduced performance and impacts on well-being, especially in cognitive demanding environments (Liebl, et al., 2012) (Scannell, Hodgson, García Moreno Villarreal, & Gifford, 2016) (Kristiansen, Persson, Lund, Shibuya, & Nielsen, 2013).

On the other hand, lack of background noise means that conversations can be more intelligible and overheard easier. This can not only result in increased distractions, it can also result in reduced subjective speech performance.

Various measures can be considered to improve the acoustics of spaces, one of which is the strategic use of sound masking. Sound masking is the process of adding background sound to reduce noise distractions, protect speech privacy and increase office comfort. Benefits and application of sound masking for improved subjective speech privacy is well established. In particular in areas where elevated privacy requirements apply (e.g. outside executive suites, meeting rooms, pods) or where discrete sound is desirable (e.g. where areas are 'too quiet'). Appropriate speech privacy between two spaces depends not only on partition sound insulation but also on background noise levels within the receiving room. Higher speech privacy outcomes can be achieved with increased overall sound insulation performance of the separating partition. This, however, typically translates into more substantial wall and partition constructions with additional mass and material which in turn result in increased overall project cost, complexity as well as carbon footprint.

Construction industry carbon footprint is a significant contributor to global carbon emissions associated with the production, transportation, and installation of building materials, as well as their disposal (United Nations Environment Programme, 2023). As the operational carbon from buildings is being reduced through strategies such as better energy performance, use of renewables, embodied carbon of construction materials becomes a larger portion of a building's total lifecycle emissions.

Same speech privacy outcomes can be achieved by reducing the sound insulation performance of the partition while increasing the background noise level and in turn reducing the overall partition build-ups and carbon footprint. This paper explores the opportunities of sound masking as a possible tool to assist with a low carbon design through reduction of overall partition build-ups and consequently the embodied carbon footprint of a project.

2 NET-ZERO CARBON

The planet's current state with respect to global warming is increasingly concerning with adverse impacts from human-caused climate change expected to continue to intensify (Intergovernmental Panel on Climate Change, 2023). Significant actions are required to reduce the Greenhouse Gas (GHG) emissions by 2030 to avoid crossing the 1.5 ºC threshold in line with the Paris Agreement. Achieving net-zero carbon is imperative in mitigation of global warming and preventing sever, costly and irreversible environmental impacts as well as enabling a sustainable future for all living organisms.

Net-zero carbon generally refers to achieving an overall balance between the greenhouse gas emissions produced and those taken out of the atmosphere through various process including that of natural and human processes. Zero-carbon on the other hand generally refers to a product or service that has no carbon emission. To mitigate the climate catastrophe and pave the way for a sustainable future for next generations, we need to get close as possible to zero carbon and only rely on offsetting when absolutely necessary (Climate Council of Australia, 2023).

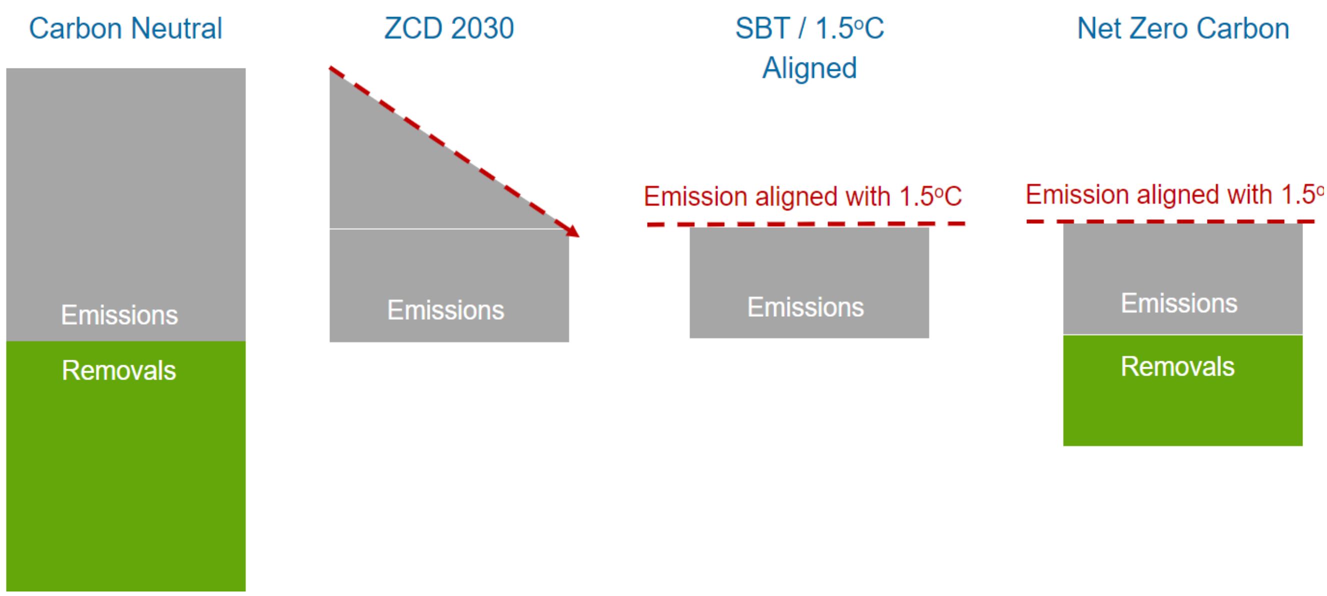


Figure 1 – Steps along the net zero carbon journey

The built environment sector is one of the largest contributors to the greenhouse gas emissions accounting for about 37 percent of the global emissions (United Nations Environment Programme, 2023). Building construction materials and processes for main construction materials account for about 9% (United Nations Environment Programme, 2023). This highlights the need for strategies to reduce carbon footprint and facilitate a low carbon design.

3 SPEECH PRIVACY

Speech privacy is essential in building and room acoustics design, as it ensures conversations in acoustically sensitive spaces are unintelligible to unintended listeners in adjoining areas. Speech privacy relates directly to speech intelligibility—how well speech can be distinguished and understood. It can be achieved through two main methods: enhancing the sound insulation of the separating partition or increasing background sound levels to mask speech.

Various metrics are used to assess speech privacy including Articulation and Privacy Indices (AI and PI) used mainly in open plan offices as defined in ASTM E1130. Speech Intelligibility Index (SII) and Speech Transmission Index (STI) as defined in ANSI/ASA S3.5-1997 (R2020) and IEC 60268-16 both of which are similarly mainly used to assess speech privacy for communication systems and open plan offices.

Common metrics used for assessment of speech privacy between spaces include the Speech Privacy Rating as well as Speech Privacy Class. Speech Privacy Rating (PR) is an industry accepted metric defined as the arithmetic summation of the overall partition sound insulation performance rating and background noise within the receiving space. It follows the relationship between the background noise and sound insulation performance within which different levels of privacy have been observed.

The Speech Privacy Class (SPC) is based on statistical analysis and methodology developed by Bradley and Gover (Bradley & Gover, 2010) as adopted in ASTM E2638-10. Similar to Speech Privacy Rating (PR), the Speech Privacy Class (SPC) is calculated based on arithmetic summation of a calculated level different and background noise level parameters. However, the calculated level difference and background noise level unlike the Speech Privacy Rating (PR) are calculated based on arithmetic average of the 1/3 octave values between 160 Hz to 5000 Hz compared to the overall weighted level different and a-weighted background noise levels as used for Speech Privacy Rating.

The other difference between the commonly used Speech Privacy Rating (PR) and Speech privacy Class (SPC) is the SPC also provides information on frequency of intelligibility for a particular speech level and correlates more closely with Speech intelligibility metrics such as Articulation Index (AI).

Work done by Salter et al. 2003 also proposed a method to predict speech privacy in workplaces which can be used for both open plan as well as assessment of speech privacy between enclosed spaces. The Speech Privacy Predictor (SPP) as defined by Salter et al. 2003 focuses on prediction of level of dissatisfaction for a given subjective speech outcome.

Key factors influencing speech privacy are the background noise level and sound insulation performance of the separating partition. A general rule is that a 5 dB increase in background noise can offset a similar reduction in sound insulation, achieving comparable privacy outcomes and reducing the partition buildup and ultimately its carbon footprint. Sound masking is an effective way to raise background noise in a controlled manner, optimising both level and spectrum for the desired privacy.

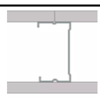
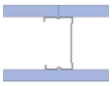
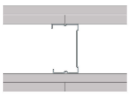
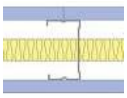
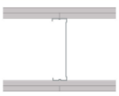
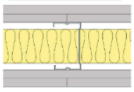
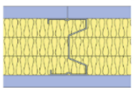
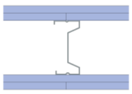
4 SOUND INSULATION

Embodied carbon of partitions typically comprises of a large portion of the overall project carbon footprint. The typical drywall internal partitions buildups consist of multiple layers of internal lining, insulation and structural framework which all consists of relatively carbon heavy material. Reducing the buildup of the internal partitions where practical can result in somewhat notable saving in project embodied carbon.

Acoustic performance requirements are only one consideration in selection of internal wall buildup with other consideration such as fire protection, thermal comfort and structural requirements also play an important role. However, quiet often acoustic performance requirements drive the need for more onerous constructions and buildups in particular for projects where speech privacy and sound transmission control are critical.

For most spaces where some level of speech privacy is required such as offices, meeting rooms and the like, partition sound insulation performance is typically designed to achieve a weighted airborne sound reduction index of R_W 40 – 50. The R_W 45 sound insulation rating is also the minimum required performance for Green Star Acoustic Comfort – Acoustic Separation performance requirements. Other sustainability acoustic performance requirements such as WELL, BREAM, and LEED also adopt similar and higher sound insulation performance requirements. Table 1 presents a selection of typical lightweight wall options with steel studs with weighted airborne sound reduction index performances of R_W 35 to 55. The estimated embodied carbon for each partition configuration indicates that a 5 dB increase in acoustic performance could potentially result in an increase of embodied carbon by up to 50% depending on the buildup. These figures are however indicative and will hugely depend on the wall buildup strategy and the additional treatment required to achieve the increase in the acoustic performance (e.g. if additional linings or insulation or combination of all is required). Additionally, these figures are based on an 8m wide by 3.5m high partition (28 m^2) and are representative of the upfront embodied carbon values. Furthermore, the figures are based on UK market and include figures for manufacturing and transport within UK. These figures are expected to be different in other regions and in particular Australia. Regardless, they provide an insight into the extent of likely increase in embodied carbon content of partitions with increase in acoustic performance.

Table 1 – Example acoustic rated partitions and embodied carbon content

Partition type (British Gypsum reference		**Sound Insulation Rating, dB R_w**	**Embodied Carbon, GWP kgCO2eq**
A206013		36	**249**
A206164		40	**270**
A206015		45	**356**
A206196		45	**284**
A206027		50	**424**
A206142		50	**374**
A206A252		50	**356**
A206A289S		55	**485**

5 SOUND MASKING

5.1 Potential

Sound masking can provide a means to offset the increase in sound insulation performance of the partitions for a given desired speech privacy outcome. The sound masking provides a consistent, unobtrusive background sound through a network of speakers strategically placed in a space. Typical components of a sound masking system may include the signal generator, amplifiers, speaker or emitters, controller or processor, sensors or microphones in adaptive systems, as well as the software interface. All of which inherently have embodied carbon content and footprint. Additionally, the mounting system, cabling and associated electrical infrastructure needed (such as additional power, electrical boards etc) can also add to the overall embodied carbon of a sound masking system.

Currently, no sound masking product with Embodied Carbon Product Declaration (EPD) certificate is available from which a more accurate estimate of the sound masking system embodied carbon can be established. Estimating the embodied carbon for each component of a sound masking system depends on several factors, including materials, manufacturing processes, and transportation. To give some context, a representative embodied carbon value of a laptop, desktop computer and a network switch can be about 100, 200, and 350 kg CO_2e respectively (Teehan & Kandlikar, 2013) (Lövehagen, Malmodin, Bergmark, & Matinfar, 2023). A sound masking system with electronic components such as the signal generator, processor, speakers etc are not expected to have higher carbon content that such electronic component intensive equipment.

The overall embodied carbon footprint of sound masking system will also depend on the design and the requirements for the project. The ultimate footprint will depend on the extent and coverage required, number of speakers and the zoning design. These along with operational carbon of sound masking such as power usage are other factors have to be considered when assessing suitability.

However, a higher-level comparison of the likely embodied carbon of a sound masking system compared to that required for increase in sound insulation performance of partitions, indicates the merit in adopting this approach in reducing the overall embodied carbon of the project. Further study is required to identify the benefits of this, such by taking examples of fully fitted out office floorplates, including consideration for different office/occupant types (e.g. legal firms, financial services, software development), and calculating the acoustic and carbon benefits of implementing sound masking systems in specific areas and the resultant decrease in partition buildup requirements. Similar approach is adopted in WELL v2 *Feature S03 Sound Barriers – Part 1 Design for Sound Isolation at Walls and Doors* requirements where use of sound masking system allows for 5 dB lower sound insulation requirements.

5.2 Other benefits

In addition to the potential for sound masking to assist with reduction of overall construction embodied carbon footprint, the approach can bring additional benefits such as

- Productivity and wellbeing
- Cost reduction
- Robustness
- Control
- Adaptability and flexibility

Sound masking has been found to improve productivity and well-being by reducing cognitive load and improve privacy whilst creating a more consistent auditory environment (Bergefurt, Appel-Meulenbroek, & Arentze, 2024) (Hongisto, Varjo, Leppämäki, Oliva, & Hyönä, 2016) (Haapakangas, Hongisto, Kokko, & Keränen, 2014) (Jahncke, Hygge, Halin, Green, & Dimberg, 2011). Haapakangas et al. (2014) demonstrated that reducing speech intelligibility by sound masking in open-plan offices can improve cognitive performance by minimising the disruptive effects of background noise. A study carried out by Jahncke et al. (2011) found that sound-masked environments can enhance memory, comprehension, and reduce fatigue.

Reduction of partition sound insulation requirement can mean, reduction in overall build-up and cost of material. Other aspect of increased partition construction is labour costs in addition to that of the material itself. Complex constructions can result in higher labour costs increasing the overall project costs. Additionally, acoustic detailing of walls becomes more difficult and costly as the acoustic rating increases in particular for designs or retrofit projects where complex services reticulations and structural members running through sensitive spaces pose additional challenges.

To achieve satisfactory acoustic privacy outcome, a balance should be kept between the level of sound insulation of separating elements and the background noise level in receiving room. The background noise level within the space will be reliant on sources of external noise, occupancy noise and services of which they all can vary in level and frequency. Out of the above typical three sources of internal noise, the mechanical services can provide a steadier and more coherent acoustic environment within a space which can assist with masking of sound and speech. However, the acoustic environment achieved using mechanical services noise is limited to various factors. such as mechanical noise levels, layout, the room acoustics etc. Sound masking systems can be designed to provide a more steady and uniform acoustic environment compared to that can be achieved by services noise. In particular reliance on external and occupancy noise sources as well as services for a continuous un-interrupted background noise can be very difficult and risk.

A more consistent acoustic and auditory environment can be achieved through sound masking systems. This enables more control in the acoustic conditions that can be achieved within a space. The use of sound masking systems can also be used in conjunction with other AV systems and bring additional benefits such use for soundscaping, and PA/VA. More modern sound masking systems enable refined control in adjustment of the sound profile and spectrum for an enhanced overall auditory environment based on the room characteristics and acoustic properties. Features such as the adaptive control, provide the added benefit of adjustment of level and spectrum based on the actual ambient noise level changes and variation within the space.

Sound masking systems can be adjusted to suit different conditions and potential changes in use of spaces over a building life cycle such as changes in tenants and office fitout. It is easier and less costly to reconfigure a sound masking system to suit a certain environment compared to retrofit acoustic treatments to a space achieve a similar acoustic environment and outcome. Sound masking systems are also reasonably adaptable and flexible to be retrofitted in existing environments and can be implemented for various scales from a single office to large workspaces. Sound masking system used for multiple rooms for example would also mean that the embodied carbon of core system equipment will be shared across a larger scale (i.e. much lower carbon emission per room).

5.3 Things to be mindful of

Although sound masking could potentially assist with reduced carbon design for building projects, there are several aspects and limitations that affect to what extent this approach can be beneficial including sound insulation requirements, compliance with standards, ambient noise limitations, transport and operational carbon, as well as implications on other disciplines.

Benefit of sound masking for improved speech privacy is well documented and discussed. Care should be taken where certain sound insulation performance is required for sound transmission control such as that required adjacent to plant and utilities or spaces with high noise activity. Similarly, in projects where certain minimum sound insulation performance requirements are applicable such that under sustainability schemes, client briefs or building design standard requirements, benefit of above approach can be limited.

Sound masking provides enhanced acoustic environment via elevating background noise, masking the unwanted and distracting sounds. However, there is limit in terms of maximum suitable ambient noise levels for different spaces. Studies have shown that typically overall noise levels exceeding 48 dBA including the services, external and sound masking can have adverse impact. Therefore, the benefit of sound masking can be limited in cases where high existing ambient noise exists.

An important factor to be mindful is the transportation as well as operational carbon for such systems. The transportation carbon footprint of such systems can outweigh that for the building material which can typically be mostly sourced locally compared to products that are supplied through overseas networks. Additionally, the additional operational carbon of sound masking system due to increased power demand and electricity should also be considered. Although, for more modern systems, the large component of the sound masking system being the speakers, are generally Power Over Ethernet which should not significantly increase the electrical load. Moreover, with global progress in more energy efficient buildings and use of green power, this is likely a less limiting factor. Strategies such as integration with existing AV systems or re-use of existing speaker systems where possible can also assist with lowering the increase in operational embodied carbon of sound masking systems.

Implications of sound masking system and design on other disciplines should also be considered. Cost and time for installations, coordination of the system with other services and disciplines, additional spatial and infrastructure requirements (electrical switchboard, increased power, space for units, etc), likely interference with other AV systems and performance, are examples of such implication on other disciplines which require careful consideration.

6 CONCLUSIONS

This paper has explored use of sound masking as a potential tool to assist with reducing overall embodied carbon through offsetting higher sound insulation solutions for achieving effective speech privacy in building acoustics. By elevating background noise levels, sound masking can reduce the demand for extensive partition build-ups, offering an opportunity to lower embodied carbon in construction while maintaining or even enhancing acoustic privacy and environment. Given the pressing need to minimise greenhouse gas emissions in line with net-zero goals, sound masking provides a potential approach to balancing acoustic performance and environmental impact.

While the benefits of sound masking in terms of adaptability, cost-effectiveness, and occupant well-being are substantial and well understood, its practical application with respect to reduced carbon design requires careful consideration. Information on the embodied carbon of sound masking systems is not widely available and present an area of further study. Factors such as the embodied and operational carbon footprint of sound masking systems, potential limitations in high-noise environments, and the integration with other building systems must be considered when assessing effectiveness of such approach for low carbon design.

Sound masking, therefore, stands as a flexible, scalable tool that can assist with sustainable acoustic design. By reducing reliance on heavy, carbon-intensive materials, it offers a pathway toward a more resilient, eco-friendly built environment, aligning with both functional and environmental objectives. Future research and continued technological advancements could further enhance its potential as a component in sustainable building design. Further studies are needed to evaluate the benefits of this approach through review and assessment of case studies within the built environment.

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