

# EVIDENCE REVIEW FOR EFFECTS OF SOUNDPROOFING ON RESIDENTS' WELLBEING AND ALTERNATIVE DESIGNS

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## 1 INTRODUCTION

This paper describes a project undertaken by the SIENA Consortium (Sustainable Infrastructure and Evidence for Noise and Air), commissioned by the UK Department for Environment, Food and Rural Affairs, and suggested by the Welsh Government, to deliver an 'Evidence Review for the Effects of Soundproofing on Residents' Mental Wellbeing and Alternative Designs'.

In the context of publications and guidance specifying targets for maximum recommended sound levels inside dwellings from external sound sources, and the drive to improve thermal efficiency and airtightness, the project sought to determine if there is a minimum audibility of external sound within dwellings for optimal health and wellbeing.

At the outset of the project, the funders identified nine questions that were of interest in relation to residents' wellbeing, mental health and perceptions, as well as unintended consequences of soundproofing and alternatives. These are listed below:

### *"Residents' Wellbeing, Mental Health and Perceptions"*

- 1) What evidence is there, if any, on the types of sounds that residents do want to hear (e.g., birdsongs and neighbours chatting in the street)? How do residents view the fact that some of the sounds they like to hear are being blocked/reduced by insulation?
- 2) For people who are predominantly or entirely housebound (physically, or for occupational, cultural, financial or any other reasons) and alone, what may the mental health and wellbeing consequences be of being able to hear only indoor sounds most of the time, as opposed to also hearing, e.g., cars go past, birds, rain, children playing?
- 3) What is the evidence of the positive and negative effects of the societal shift towards doing more office work from home, in terms of noise, soundscape, and privacy to residents (including vulnerable groups)?

### *Unintended Consequences of Soundproofing and Alternatives*

- 4) How can the concept of "good acoustic design" achieve an optimal balance of minimising noise exposure while preserving the outdoor sounds that people might wish to remain audible inside buildings?

- 5) At what point / in what circumstances might increasing the soundproofing of a building façade decrease internal soundscape quality / occupants' wellbeing?
- 6) At what point / in what circumstances might reducing the soundproofing of a building façade increase internal soundscape quality / occupants' wellbeing?
- 7) Which groups of people (e.g., the sick, elderly, housebound, lone home office workers and others) and living settings (e.g., care settings, detached and terraced properties, apartments/flats) should receive the greatest consideration when it comes to avoiding acoustic isolation?
- 8) If the evidence suggests that more enjoyable sounds should be allowed to penetrate through walls for residents' wellbeing and mental health, what guidance could be provided for construction works?
- 9) What guidance can be offered (if necessary) for (a) sound level and (b) design (to achieve those levels identified in (a)) to those designing residential buildings (including care settings), on striking the optimal balance between protection from unhealthy noise and maintaining an acoustic connection with and consciousness of the outside world, to support mental wellbeing?"

In order to address the nine questions posed within the Specification three work packages were undertaken:

- 1) Work package one focused on examining how the concept of "good acoustic design" can achieve an optimal balance of minimising noise exposure while preserving the outdoor sounds that people might wish to remain audible inside buildings.
- 2) Work package two carried out a systematic review to investigate the evidence for effects of indoor sound environments on mental health, wellbeing, quality of life, annoyance and sleep. The review focused on exploring the health consequences of the internal soundscape, particularly for vulnerable individuals who may spend a high proportion of their time indoors.
- 3) Work package three examined soundscapes and non-acoustic factors (NAFs). The concept of salutogenesis (health promotion by moving away from negative and/or undesirable actions/activities and towards desirable actions/activities to attain positive outcomes) was applied to consider the NAFs critical to accurately interpret acoustics and soundscape data to inform design and planning options. NAFs are also critical to understanding factors influencing annoyance as a health outcome through the indirect pathway, emphasising the need for a holistic approach to assessing sound environments.

## **2 SYSTEMATIC REVIEW**

### **2.1 SCOPE AND METHOD**

This work was led by Professor Charlotte Clark, with assistance from Kathryn Willis and Dr Elena Marcus. A systematic review was carried out to examine the research question "What are the effects of indoor sound environments on mental health, wellbeing, quality of life, annoyance and sleep?" The review identified original, primary quantitative and qualitative research papers. Search terms were identified to cover both positive and negative effects of sound. The focus was on indoor sound environments but also included studies examining how external sound sources are perceived within the indoor residential environment. Search terms to identify epidemiological (cohort studies, cross-sectional surveys), as well as experimental, laboratory and qualitative research studies were used. Web of Science and PubMed were searched for papers published in English between 1<sup>st</sup> January 2019 and 31<sup>st</sup> January 2023. Due to time constraints and maintaining a pool of peer reviewed conference abstracts were not searched.

Papers were assessed using the following PECO criteria (Population Exposure Comparator Outcomes):

- Population: the inclusion criteria will be studies of the general population or specific sub-groups of the population in any residential and home settings (including care homes).

- Exposure: the inclusion criteria will be any exposure to sound or noise, from a range of sources. Included studies could either measure or calculate noise exposure levels expressed in decibel values at an appropriate location for the study participants' residence or be subjective ratings of noise and sound.
- Comparator: no noise or a lower noise exposure (however, having a comparator was not always a requirement for the papers identified).
- Outcome: from medical records or interviews using a known scale or validated standardised assessment method or that the outcome was self-reported from a questionnaire or interview.

All papers were assessed for bias considering factors such as the representativeness of the sample, the quality of the outcome assessment, the quality of the assessment of sound and/or noise exposure, and whether the analyses took confounding factors into account (i.e., other important predictors of the exposure or outcome).

Quantitative papers were then assessed using the GRADE methodology, recommended by the WHO Handbook for Guideline Development<sup>8</sup> and adapted for use in the WHO Environmental Noise Guidelines for the European Region<sup>9</sup> to interpret the overall quality of evidence available for a specific noise/sound source and health outcome. The GRADE methodology ranks the quality of evidence as 'high', 'moderate', 'low', or 'very low'. Qualitative papers were assessed using the GRADE-CERQual method which assesses how much confidence to place in findings from systematic reviews of qualitative research<sup>10</sup>, which rates the confidence in the evidence as 'high', 'moderate', 'low' and 'very low'.

## 2.2 RESULTS OF THE SYSTEMATIC REVIEW

The systematic review identified 59 studies which were analysed. Initially, 73 papers were retrieved for consideration, one paper could not be located and 13 were excluded after full paper review. Studies used survey methodologies or were experimental laboratory-based methodologies.

Studies were drawn from a range of continents and countries, including Asia (China, Japan, Singapore, South Korea), Europe (Bulgaria, Italy, the Netherlands, Slovakia, Sweden, Spain), Afghanistan, Australia, India, and Canada. Only ten studies included the United Kingdom. Studies examined adult or elderly adult populations. Studies examined a range of wellbeing outcomes (annoyance, stress, anxiety), as well as perceptions such as pleasantness and eventfulness. Some papers were focused on how COVID-19 changed people's experience of sound in their dwellings.

It is beyond the scope of this paper to report the detailed data extraction and GRADE assessments, but the strength of the evidence is summarised below in Table 1. The review found that the quality of the quantitative evidence when considered across the studies is of moderate quality for a couple of outcomes, e.g., the effects and changes to sound and noise associated with COVID-19 and residential care homes and dementia. It was of weaker quality for general adult populations (both in the survey and experimental studies), the elderly, and WFH populations, indicative of effects for other outcomes such as residential settings and effects on wellbeing and perceptions.

This review found that the quality of the qualitative evidence when considered across the studies is of 'very low quality' for effects on wellbeing and perceptions for general adult populations, the elderly and WFH populations, as well as for the effects and changes to sound and noise associated with COVID-19 and residential care homes and dementia.

Table 1: GRADE assessments for the strength of the quantitative evidence and the confidence of the qualitative evidence

Relationship	GRADE evidence rating – Quantitative Evidence	GRADE-CERQual evidence rating – Qualitative Evidence
Residential settings and effects on wellbeing and perceptions: general adult populations	Very low quality	Very low confidence
Surveys of residential settings and effects on wellbeing and perceptions: elderly populations	Very low quality	Very low confidence
Surveys of residential settings and effects on wellbeing and perceptions: WFH populations	Low quality	Very low confidence
Effects and changes to sound and noise associated with COVID-19	Moderate quality	Very low confidence
Experimental studies of residential settings and effects on wellbeing	Very low quality	n.a.
Residential care homes and dementia	Moderate quality	Very low confidence

It was noted that methodologically, many of the papers were rated as having high bias. The sampling framework for studies was often unclear and poorly reported, potentially influencing the representativeness of the sample and the generalisability of the findings. The term ‘soundscape’ was commonly used but only a few studies reported using the ISO Soundscape approaches and methods<sup>11-13</sup>. Few studies evaluated interventions or used longitudinal ‘before and after’ methodologies. Few studies collected detailed information about the residential building type or design and building factors that might influence sound/noise and wellbeing, limiting the development of knowledge needed for the field. Studies need to evaluate effects in relation to specific aspects of the dwelling/built environment. The quality of the statistical analysis and qualitative analyses was often poor. Few quantitative studies reported multivariate statistical analyses or adjusted for other potential confounding factors.

The conclusions, about the quality of the evidence are impacted by the low number of studies available for most of the outcomes. This lack of evidence does not necessarily mean that there are no effects of sound on mental health, wellbeing, quality of life, annoyance, and sleep, rather that they have not yet been the focus of enough methodologically robust studies.

### 2.3 REPORTING CHECKLIST

The findings of the systematic review, along with findings from the Good Acoustic Design section, have informed the development of the checklist for reporting studies that would improve the quality of the studies and the evidence going forward (see Table 2).

Table 2: Checklist for reporting studies about sound and residential wellbeing

Study aspect	Reporting
<b>Outcome assessment</b>	
Mental health, wellbeing, quality of life, sleep	Use standardised, psychometrically robust questions, where available. For example, established psychological scales measuring a specific psychological outcome or concept, or established sleep disturbance questions assessing awakenings, time to sleep, sleep quality, etc. This will improve and ensure the validity of assessments, and the potential to compare findings across studies.
Annoyance	Use the ISO15666 annoyance technical standard <sup>14,15</sup> to assess annoyance. This will improve and ensure the validity of assessments, and the potential to compare findings across studies.

<b>Sampling</b>	
Target population, or approach to sampling for the study	Provide a clear definition of the 'target' population for the study in the method.
	Provide details of how the population were identified for sampling in the method. (Could the sampling be undertaken to improve the generalisability of the findings?)
	Report the response rate in the method section (NB: this will not be possible for 'snowball' sampling approaches).
	Include a statement about the choice of sample size (power calculations, if relevant) in the method. Include a statement in the discussion about how the sample size might have influenced the findings.
	Make a clear statement in the discussion about how 'representative' the achieved sample was of the 'target' population.
	In the discussion include a statement about how sampling may have influenced the findings in the discussion and for which populations they are and are not potentially valid.
<b>Statistical analysis for quantitative studies</b>	
Hypotheses	Clearly state which hypotheses are being tested.
Analysis plan	Ensure an analysis plan is developed at the start of the project.
Statistical testing	Report multivariate statistical analyses that address clearly stated hypotheses. Limit descriptive analyses to describing the sample and outcomes, where possible.
Confounding factors	Analyses should adjust for confounding factors that may influence the relationship observed between sound and mental health, wellbeing, quality of life, annoyance, and sleep, as well as factors that may influence residential and dwelling aspects.
<b>Analysis for qualitative studies</b>	
Method of analysis	Report the method of qualitative analysis used to address the research aims and hypotheses.
	Clearly evidence the analysis process, including evidencing how the qualitative data was undertaken and analysed (e.g., if undertaking thematic analysis, provide a thematic framework linked to data).

### 3 GOOD ACOUSTIC DESIGN

#### 3.1 DEFINITION

The understanding of what 'Good Acoustic Design' is intended to mean is informed by the definition within ProPG Noise & Planning, Supplementary Document 2 (2017)<sup>1</sup> and is sufficiently broad to apply to the approach that can be taken in planning façade design but also in the structural design that affects internal sound insulation. ProPG says:

*“good acoustic design is about more than the numbers. It is a holistic design process that creates places that are both comfortable and attractive to live in, where acoustics is considered integral to the living environment.”*

### 3.2 DISCUSSION ON HOW GOOD ACOUSTIC DESIGN CAN BE SUPPORTIVE OF HEALTH AND WELLBEING

Peter Rogers is the lead author of this section with input from Angela Lamacraft, and any opinions expressed in this section are principally his. The evidence identified within the systematic review identified an embryonic evidence base which informed a discussion based on opinions of how good acoustic design may achieve conditions that are supportive of occupants' health and wellbeing. The aim of it was to discuss how it may be possible to optimise the design of homes to be suitable for the wide range of intended activities that take place within them, to inform future studies and to identify ways in which acousticians can work with other disciplines to evolve the design approach of future homes. COVID-19 has shown the range of activities to now be wider than it has been historically, including work, education and fitness uses and the need for greater levels of privacy and sound insulation, yet there is also a need to consider the quality of the indoor soundscape and how it connects the occupants with the world around them. This is how the good acoustic design of homes may be able to make homes fit for the future, whether they are re-use of existing housing stock or new build. A human centric design approach is considered, which aims to deliver sustainable development that is also restorative. It is necessary for each home to 'work' for the occupants over the lifetime of the building, which ultimately means it must be supportive of health and wellbeing so that the resources used to create the building are not wasted and therefore become unsustainable. In this way good acoustic design can complement good eco-credentials and net zero energy buildings to achieve healthy homes that meet the sustainable aspiration of our time.

Applying a holistic or transdisciplinary approach, as the SD2 guidance suggests, begins with early involvement of an acoustician in the design process and consideration of non-acoustic factors as well as those which are acoustically quantifiable in the traditional sense. Early influence on position, orientation, layout can give people access to quiet sides for windows and ventilation route and create a design strategy for façades affected by noise pollution within the context of the locality. This may also lead to the consideration of the landscape design or connection to nature to maximise the double benefit of biodiversity net gain aims and to bring natural views and natural sounds into the locality which the indoor soundscape can benefit from. The outcomes of reduced stress and annoyance and improved self-reported acoustic comfort, wellbeing and health ratings are the objectives of this approach and could lead to poor quality environments being improved over time for the benefit of all<sup>2 3 4-6</sup>.

The use of water and vegetation in public areas is a consideration to introduce natural elements that can assist in creating more healthy soundscapes inside through acoustically permeable facade. The design of the façades is critical so that the building can also be ventilated sufficiently to deal with overheating, without compromising the internal acoustic conditions to create dwellings that support the health, comfort, and wellbeing of people.

Sound insulation remains a core consideration to suit a wide range of activities between homes and also within them, but also suitable room acoustics for the activities affects acoustic comfort within the home. Appropriate noise control of the mechanical and electrical services and technology is also needed to address noise or vibration sources where low or high frequency tonal or non-tonal sound might be generated and may affect people inside homes.

The need to satisfy multiple uses in the home, often at the same time, and make homes suitable to adapt throughout their lives is the core challenge. The diversity of occupants is the other factor, with consideration of changing physical and mental health and wellbeing challenges as people's age another factor. The following core uses reflect the author's opinion of the ways in which activities within our homes have broadened post Covid, drawing from Torrens et al 2022<sup>7</sup> and adding to that list in light of the range of activities covered over the shortlisted studies:

- Sleeping
- Relaxation physically and mentally (respite)
- Working from home (WFH) - including video conferencing

- Exercising and physical activity
- Entertainment (including music) and socialising.
- Intimacy
- Culture/ religious adaptations
- Adaption for neurodiversity & inclusion
- Adaption for aging well and dementia care (studies were largely done in care homes)
- Recouperation from physical or mental illness.

The good acoustic design considerations under each heading should aim to provide optimal conditions for each activity or integrate a focus on sound insulation and acoustic comfort, which are discussed more fully for each activity case in the coming Defra report.

Sound insulation has been shown to be a fundamental requirement in homes and care home facilities to provide sufficient acoustic privacy, acoustic comfort and to allow restorative good quality sleep, with the ability to control some types of noise ingress from outside remaining crucial to a degree. However, over-insulation of all types of sound from outside and through the structure can also lead to a lack of connection to the outside and community, and sense of isolation. Striking the right balance is therefore important when designing homes for health and wellbeing, with good acoustic design able to address many of the diverse needs.

The review of recent evidence on indoor sound environments and their effects on mental health, wellbeing, quality of life, annoyance and sleep has revealed some tentative findings and key considerations for the role of sound insulation and good acoustic design. Good acoustic design should include appropriate sound insulation which aims to optimise indoor spaces for the diverse range of activities needed to support occupants, with a particular focus on internal sound environments that support sleeping well, relaxing, working/learning, exercising, socialising, intimacy, cultural needs, neurodiversity, catering for aging well and recovery from or coping with illness such as dementia, or disease.

## 4 SOUNDSCAPES AND NON-ACOUSTIC FACTORS (NAFS)

### 4.1 INDOOR SOUNDSCAPING

This work was led by Jian Kang, and the following represents his views. While soundscape studies have traditionally involved urban areas and outdoor spaces, indoor soundscape research has been gaining momentum in recent years to address the perceived acoustic quality of indoor built environments. Like the situation for outdoor spaces, for indoor spaces, conventional approaches mainly concentrate on technical indices such as background noise level, level of sound transmission and reverberation, where the acoustic comfort, considering different people's needs, in context, has been paid less attention. Indeed, measuring people's perception is essential for the design of high-quality soundscapes.

Based on the systematic review, it is shown that while the key issues in indoor soundscaping have been covered in the literature, more in-depth and rigorous studies are needed, considering:

- Establishment of indoor soundscaping frameworks for different kinds of spaces;
- More rigorous study design and analysis;
- More longitudinal studies;
- More intervention studies; and
- The UK context.

### 4.2 NON-ACOUSTIC FACTORS

This work was led by Lisa Lavia and the following reflects her views. Non-acoustic factors have been found to account for at least one-third of the human response to sound in context<sup>16</sup>. Work to develop

an International Standard (ISO/AWI TS 16755-1 Acoustics — Non-acoustic factors — Part 1: Definition and conceptual framework) on non-acoustic factors is underway via ISO/TC43/SC1/WG68. This work is being led internationally by the UK in the BSI EH/1/3 committee on Residential and Industrial Noise. The proposed standard, introduced in November 2022, is in the Working Draft stage and proffers a definition of non-acoustic factors, based on the literature, as: *“All factors other than the objective, measured or modelled acoustic parameters which influence the process of perceiving, experiencing and/or understanding an acoustic environment in context, without being part of the causal chain of this process.”*<sup>17</sup> N.B. This definition is currently being consulted on via the relevant ISO and BSI committees and may be subject to change. However, it seeks to bring together a range of views on non-acoustic factors into an agreed definition and provides an overarching framework wherein various acoustic and other disciplines can intersect.

The evidence from the systematic review shows effects of non-acoustic factors related to mental health (e.g. depression, anxiety, coping ability); wellbeing (e.g. physical and mental distress, sense of safety, restoration, vulnerability); quality of life (e.g. impacts on daily activities including working/studying from home, conflicts with neighbours); annoyance (including noise sensitivity, perceived loudness and cumulative effects of noise over time); and sleep (e.g. the impact of non-acoustic factors on quality of sleep, for example feeling safe at night in relation to the sound environment). These effects span four dimensions of non-acoustic factors: personal, tangible, psychosocial and contextual/situational<sup>17 18</sup>. The findings overall were as expected, in line with previous literature and further illustrate the outsized impact of non-acoustic factors on the human perception of sound and on mental and physical health, wellbeing and quality of life. The findings emphasise the critical importance of designing/adapting/renovating/upgrading indoor sound environments for use cases aligned to public, community and individual health and wellbeing outcomes in relation to combined indoor and outdoor local environmental quality. Given the complex, multi-factorial nature of non-acoustic factors, transdisciplinary research is needed in the UK to build on the existing corpus of international studies. The need for an integrated transdisciplinary approach is identified as a way forward to agree frameworks for harmonised data collection and assessment across multiple disciplines (e.g., acoustics, medicine, psychology, physiology, architecture, human geography) and applications (e.g., environmental quality, placemaking, biodiversity, planning, building services).

## **5 CONCLUSIONS**

This paper gives a brief overview of a series of work packages undertaken to explore the issue of the effects of soundproofing on residents' mental wellbeing and provides a checklist against which to design further research that would achieve the appropriate quality and confidence.

Recommendations for areas for further work in indoor soundscapes and non-acoustic factors have been made, with discussion for the role of good acoustic design in achieving health and wellbeing outcomes for occupants for the range of activities expected of homes post COVID-19.

Good acoustic design should aim to optimise indoor spaces for the diverse range of activities. It is concluded from discussions based on opinion that considers the findings that good acoustic design (including appropriate sound insulation) is an important factor in the design of homes and care home facilities. The objectives include providing appropriate acoustic privacy for a diverse range of activities, allowing restorative sleep, productive working from home, restorative relaxing or recovery from illness amongst other things. The control of manmade noise ingress from outside remains a particular focus, however, over-insulation of all types of sound (with a particular focus on natural sound) can potentially also lead to a lack of connection to the outside and community. Striking the right balance is therefore important when considering how sound can benefit design for health and wellbeing. The details of the answers provided to the project questions raised can be found in the forthcoming Defra report. This review of recent evidence on indoor sound environments and their effects on mental health, wellbeing, quality of life, annoyance and sleep has revealed some key considerations for the role of sound insulation and good acoustic design.



Further high quality quantitative and high confidence qualitative studies are needed to develop the evidence base.

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