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# A RISK-BASED FRAMEWORK FOR ACOUSTIC ASSESSMENT OF ASHPS - FROM DOMESTIC TO COMMERCIAL APPLICATIONS

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## ABSTRACT

Air Source Heat Pumps (ASHPs) are critical for decarbonising building heating across Europe, but their widespread deployment may be hindered by inefficient, inconsistent acoustic assessment methodologies. Through detailed acoustic modelling of realistic scenarios, we demonstrate that the UK's national calculation methodology for permitted development rights (MCS 020) can consistently predict sound levels 5-7 dB higher than calculations to ISO 9613-2. We propose a hierarchical assessment framework where evaluation complexity aligns with installation risk: from simplified MCS-based screening for domestic and commercial installations to more detailed evaluation where necessary. Our analysis addresses both domestic and non-domestic contexts, examining specific challenges around source characterisation, operational patterns, and cumulative impacts. For non-domestic installations, we identify particular issues regarding low-frequency emissions and night-time operation. Critical areas for further research include validation of propagation models, systematic post-installation studies, and standardised approaches to character corrections in the absence of data at the design stage. This framework could significantly reduce barriers to ASHP adoption by making assessments more efficient and consistent while ensuring appropriate acoustic protection as deployment scales up to meet decarbonisation targets.

**Keywords:** ***ASHP, acoustics, noise, planning.***

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## 1. INTRODUCTION

This paper critically examines current acoustic assessment methodologies for Air Source Heat Pumps (ASHPs) in the UK and proposes a risk-based framework to streamline evaluation while maintaining appropriate sound protection. First, we analyse the limitations of existing assessment approaches by comparing predicted sound levels using different methodologies. Then, we propose a hierarchical framework where assessment detail aligns with installation complexity and risk. Finally, we identify key areas requiring further research to support the proposed framework, with the goal of reducing obstacles to wider ASHP adoption while maintaining community sound protection. This approach addresses both domestic and commercial installations, recognising their distinct acoustic challenges while seeking consistent principles for assessment.

### 1.1 Background

Air source heat pumps (ASHPs) play a crucial role in decarbonising heating across all building sectors. Their successful integration into our built environment necessitates addressing sound emissions, which vary significantly between domestic and commercial installations. While domestic installations typically involve units of 3-16 kW heat output capacity mounted at ground level, commercial installations can be orders of magnitude larger and are often mounted on rooftops or in service yards, presenting distinct acoustic challenges.

### 1.2 Current planning regime

For domestic units the Microgeneration Certification Scheme 020 standard (MCS 020) [1] provides a simplified assessment framework that enables Permitted Development Rights (PDR), which therefore avoids the planning process. However, PDR do not apply to all domestic installations, and if the proposed installation does not comply with MCS

020 then full planning permission is required. Non-domestic installations typically require planning permission and are usually assessed using BS 4142 [2], though this standard was not specifically developed for heat pump applications, but industrial and commercial sound sources in general.

### 1.3 Opportunity to simplify the acoustic assessment

Through comprehensive acoustic modelling of realistic scenarios, we have previously demonstrated [3] that the MCS 020 method can consistently predict sound levels 5 -7 dB higher than ISO 9613-2 [4] calculations. This potentially inherent conservatism in the MCS methodology presents an opportunity for streamlining the planning process. For full planning applications, current reliance on BS 4142 introduces specific challenges around background sound level determination and character corrections that cannot be reliably predicted at design stage; in addition, different local planning authorities have different standards for noise impact assessments using BS 4142. These uncertainties introduce additional risk to the acoustic assessment and may also mean inconsistencies between practitioners. Our analysis indicates that a more structured, hierarchical approach to assessment could benefit both sectors.

### 1.4 More work is needed!

While this paper proposes a framework for determining an appropriate assessment methodology based on risk of adverse outcomes, this would require the consent of planning authorities to become a practical reality. Critical areas for further research are identified, including validation of propagation models and systematic post-installation studies, to inform future standards and ensure a suitable balance between facilitating ASHP adoption and community sound management.

### 1.5 Considerations for acoustic planning

To undertake the acoustic design for a new sound source, it is necessary to consider three distinct aspects of the sound:

- Source characterisation
- Propagation model
- Impact assessment

These aspects are considered in turn. See section 3 for a description of sound propagation modelling (the differences between those methods used in MCS 020 and typically adopted in BS 4142), and section 4 for a description of sound impact assessment methods.

## 2. CHARACTERISATION OF THE SOUND SOURCE

### 2.1 Sound power level

To comply with European Directive 813/2013 [5], ASHPs sold in the UK must declare their rated sound power level. The various EN Standards required to describe how the heat pump should be mounted in the laboratory, the environmental conditions, the water flow and return conditions, are described in [3, 5]. However, the heating load point is described in the EU Directive itself and has some ambiguity within it; manufacturers believe that the sound power test carried out at around 40 % of full load is compliant with the EU Directive, and therefore this is what they do to declare the ErP Sound Power Level, SWL, on the product label.
As there is no other description of the load point, a “full load” test does not have a formal definition and is not standardised. However, in other countries there appears to be data available for both the ErP sound power and “full load” or “maximum” sound power, such as in the German heat pump association’s online calculator [6]. A sample of data from the German website suggests that the maximum sound power may be up to 15 dB more than the ErP sound power, or it may have the same value. The sample data suggests that at sound power levels below 60 dBA the maximum sound power diverges more significantly from the ErP sound power. A discrepancy between the ErP stated sound power and actual maximum sound power introduces uncertainty into the assessment which is impossible to quantify if the data is not available.
For commercial units, source characterisation presents additional challenges. While domestic units must declare their ErP sound power level, commercial units often come with limited acoustic data. Manufacturers may report sound pressure levels at specified distances rather than sound power tests undertaken according to recognised standards.
The operating conditions under which acoustic data is measured may not reflect real-world operation. Literature describing in-situ measurements and comparison with manufacturer’s laboratory test data suggests discrepancies can be significant.

### 2.2 Tonality

Some countries include a penalty for tonality in the assessment at design stage, as can be seen on the German heat pump association website. The information on the German website indicates a “surcharge” (penalty) for tonality, $K_T$. The accompanying information notes indicate that a penalty shall be set at 3 or 6 dB, depending on the

degree of conspicuity. The tonal quality of a sound can also be determined by measurement (DIN 45681, draft edition May 1992).
Note that DIN 45681 [7] can only be applied in-situ for the determination of tones. Current practical methods for assessing tonality are hotly debated – three methods are described in BS 4142, with the preferred being the subjective method. This is not possible at the design stage without full auralisation of the sound – which requires directional information of the sound source, and an auralisation of the background sound. Our random sampling of manufacturers and models in the German database has not revealed any units that have a $K_T$ (tonality) penalty.
There is no standardised information available from suppliers in the UK that indicates tonality of ASHP units. It has been mentioned previously [8] that including a characterisation for tonality may facilitate consistency in assessments, but this information is not currently available.
While it is currently not possible to carry out a representative tonality assessment at the design stage, new methods are currently being proposed [9]. Practitioners must often make assumptions about character corrections without having the detailed spectral data that would inform a more nuanced assessment. The MCS 020 procedure does not take account of tonality.

### 2.3 Low frequency sound

When spectral data is provided, it typically excludes frequencies in and below the 63 Hz octave band, yet low frequency sound can be significant for both small and particularly for larger units. The laboratory standards disregard all sound below the 100 Hz third octave band, as laboratories are typically not big enough to reliably measure at lower frequencies.
Some countries have anomalies, such as the Netherlands; the in-situ standard for ASHPs includes a low frequency criterion, but the information is not available at design stage to assess for this outcome. Where design stage assessment differs from in-situ assessment this introduces a risk for the designers, who respond by taking a prudent approach. This potentially hinders the rollout of ASHPs unnecessarily, as it can entail an unnecessary constraint where there are little or low levels of sound character.

### 2.4 Directionality

Directional characteristics are also not required to be measured according to the standards. There is only one facility in the UK for measuring the sound power of ASHPs, at BSRIA. Laboratory measurements require a thermo-acoustic chamber, which may be either a reverberation room or a (semi or full) anechoic chamber. Directional sound is only possible to measure in an anechoic chamber, while the facility at BSRIA is a reverberation room.
Many laboratories across Europe are starting to measure the directional characteristics of ASHPs [10]; this necessitates recording both temporal and spatial characteristics of the sound, i.e. the quantity of data recorded is many orders of magnitude greater than for a simple sound power characterisation. Methods to use this data and predict in-situ impacts will also need to be developed, such methods are currently the demise of research institutions and significant project effort.

### 2.5 Operating conditions and background variations

In operation, the ASHP output is modulated to match the load. The main sources of noise, the compressor and fan, have their speeds and load adjusted, typically to optimise energy efficiency for a given output demand. The background sound level generally varies throughout the nighttime period, typically being lowest in the early hours of the morning. Many manufacturers provide a “low noise mode” for places where there are separate daytime and nighttime noise level limits. While low noise mode operation may reduce the thermal efficiency, its adverse effect is likely to be much less than provision of an acoustic enclosure, for example, or other forms of mitigation.
A “worst case scenario” approach to assessment is typical; under MCS 020 there a single noise level threshold for daytime and nighttime, with no opportunity to use a low noise mode of operation in the nighttime. A more sophisticated assessment under BS 4142 can accommodate different noise emissions in different time periods.

### 2.6 A common practitioners’ mistake

Practitioners should be wary of manufacturer's data that presents "sound level at 1 m" without accompanying sound power data. While superficially attractive for calculations, such metrics can lead to significant errors. These values typically represent measurements averaged over a control surface 1 m from the unit's dimensions, according to the laboratory test standards such as ISO 3744, ISO 3745, and ISO 3746. This is quite different from the way that practitioners often use this data – assuming a point source of sound, and a simple 20*log(r) to account for attenuation due to distance. Using these data in point-source propagation calculations systematically underestimates the source sound power level, as the total sound energy is always actually distributed over a larger measurement surface area than assumed in this calculation.

Only declared sound power levels, measured according to recognised standards, provide a reliable basis for acoustic calculations. When manufacturers present sound pressure levels at a stated distance, the unit dimensions and measurement methodology must be clearly stated to enable calculation of sound power level. A variety of reputable manufacturers appear to present data as sound levels at 1 m that encourages acousticians to make this mistake, by using an image with a “measurement location” indicated at a distance of 1 m from the unit.

## 3. SOUND PROPAGATION MODELS

When calculating the sound propagation and impact from an installation, a variety of models are available to the practitioner. Through systematic comparison of these models, we demonstrate that simpler approaches can provide inherently conservative results that may be sufficient for many scenarios. If a simple calculation demonstrates a robust case for a sufficiently low sound impact, there is no need to expend additional effort on more sophisticated modelling methods. However, simple models have risks in both directions – in simplifying the calculation of sound propagation, simple models need to be used with caution in situations that are beyond the scope of their simplifying assumptions. It can take a greater level of expertise to know when a simpler model is appropriate.

### 3.1 MCS 020 sound propagation model

As MCS 020 is applied by people with no acoustics expertise, it is based on three simple input data:

- Distance between source and assessment position, rounded down to tabulated integer values
- Number of reflecting planes (one, two or three)
- Barrier attenuation (either 0, 5 or 10 dB)

These data are used to calculate the sound propagation to the receptor location. The approach simplifies the same concepts used in ISO 9613 but treats reflecting surfaces and barriers differently. In MCS 020, each reflecting plane conceptually constrains the sound propagation to half the previously available space (solid angle), adding 3 dB to the calculated level. Our modelling has shown [3] that this in particular can consistently lead to higher predicted levels than the application of ISO 9613-2.

### 3.2 ISO 9613-2: 2024

A method identified in BS 4142 for calculating sound propagation outdoors is BS ISO 9613-2; this standard is typically applied using specialist software and expertise. The standard accounts for reflecting surfaces by calculating additional sound propagation paths for specular reflections to the receiver location. Our analysis demonstrates that this can result in predicted levels 5 - 7 dB lower than MCS calculations for equivalent scenarios.

While much more comprehensive than the MCS 020 model, ISO 9613 still has limitations when applied to the specific context of ASHP sound assessment. The standard was designed for sound propagation over longer distances and in open environments, rather than the close proximity and complex geometries often encountered around ASHP installations. The standard's assumptions about ground effects and meteorological conditions might also not be entirely suitable for the constrained urban morphologies where ASHPs are typically located.

ISO 9613 does not include wave-based sound propagation effects on tonal content, which can influence the perceived impact. There is a common misconception that ISO 9613 is “3D” modelling, as the model appears to have three dimensions. However, it is described as “2.5 D” [12], as it treats the height dimension differently to the horizontal plane .

For commercial installations, particularly those mounted on rooftops, ISO 9613-2 presents additional challenges. Rooftop installations often involve multiple units in close proximity, making it crucial to accurately model their cumulative impact. The typical lack of information about source directivity means that the manner of modelling the ASHP can become critical for determining barrier heights, for example.

## 4. SOUND IMPACT ASSESSMENT

The sound impact from a development is considered within the planning regime as part of the assessment of its environmental impact. In England this is guided by the National Planning Policy Framework (NPPF) [13]. The NPPF emphasises the need to avoid noise giving rise to significant adverse impacts on health and quality of life, and minimising any adverse effects. Further government guidance on noise is provided on the Planning Practice Guidance website [14].

The most common way that planning authorities assess noise impacts from building services plant is by applying British Standard BS 4142: 2019, "Methods for rating and assessing industrial and commercial sound." [2]. This standard provides a method for calculating a rating level that can be compared to background sound levels to determine the likely significance of the impact, depending on the context. Historically, the application of BS 4142 has been subject to varying interpretations. To address this and promote consistency, the Association of Noise Consultants (ANC) published additional guidance in the form of a Technical Note to BS 4142:2014+A1:2019. [15].

If the planning regime fails to sufficiently protect people from noise, there is statutory nuisance legislation that can be invoked under Part III of the Environmental Protection Act 1990 (EPA) [16]. A local authority has a legal obligation to investigate noise nuisance complaints under the EPA. This duty is entirely separate from its function as a planning authority, although in practice, the same environmental health or public protection officers within the local authority often handle both planning applications and nuisance complaints. In addition to complaining to the local authority, aggrieved parties can also take legal action through the courts based on private nuisance.

Under statutory nuisance legislation, there are no fixed noise levels that automatically constitute a nuisance. Instead, the judgement is made based on whether the noise is "unreasonable". Factors considered include the duration, frequency, loudness, and character of the noise, as well as the time of day and local context.

Planning seeks to achieve a high level of amenity for communities; sound impacts should be well below the threshold for a noise to be considered a statutory nuisance. Compliance with BS 4142 is typically used by local planning authorities to not just prevent a statutory nuisance, but in order to protect local amenity and quality of life.

### 4.1 MCS 020 assessment

The MCS 020 calculation includes a much-simplified sound propagation model, and has a fixed absolute impact limit of 37 dBA based on the declared (ErP) ASHP sound power level. This simple criterion takes no account of sound character such as tonality or low frequency content, and any intermittency during different phases of operation (e.g. during defrosting). The standard was developed specifically for domestic installations under Permitted Development Rights (PDR).

### 4.2 BS 4142 assessment

BS 4142 describes a process for assessing the impact of industrial or commercial sound at a receptor location – it is not designed to be used for prediction of future sound sources, although this is a common application. It is frequently used for assessment of domestic installations, despite its title "..assessment of industrial or commercial sound", suggesting that a domestic installation would fall outside of its scope.

#### *4.2.1 Background sound levels*

For new residential developments, particularly if comprising many dwellings, background levels must be predicted rather than measured. There is little experience within the acoustics industry of predicting background sound levels in new residential developments that may themselves have a significant impact on the background sound environment, for example.

In locations with low background sound levels (e.g. below 30 – 35 dBA), achieving rating levels below background may preclude viable installations, which may not be necessary to preserve quality of life for residents.

According to the National Noise Incidence Study, the percentage of dwellings exposed to background, $L_{A90,\ T}$ levels above 40 dBA is:

- 20 % of dwellings at night ($L_{A90,\ 8\ hr}$)
- 70 % of dwellings during the day ($L_{A90,\ 16\ hr}$)

In Scotland, many local authorities specify absolute limits for plant noise impact, typically adopting thresholds of NR 35 for daytime operation, and NR 25 for nighttime, internally, with open windows. It is standard practice to assume a 10 dB attenuation through the open windows, which means levels of (approximately) NR 45 daytime and NR 35 nighttime externally. NR 35 is likely to be marginally higher than 37 dBA, depending on the frequency content. This approach is not common in England, but can expedite an assessment and reduce its cost burden by omitting the background sound survey. Where the ambient sound environment is louder, and a higher sound impact may be acceptable, a dual approach can enable those assessments that benefit from a more nuanced assessment to proceed without excessive, unnecessary mitigation.

#### *4.2.2 Character corrections*

BS 4142 contains detailed guidance on decibel penalties that may be attributed to the character of sound at a receptor location – see section 2, characterisation of the sound source, for discussion of the challenges in predicting character corrections at the design stage.

In practice the background is not stationery in either time or space around a receptor location, which can make assigning character corrections contentious where sounds exist, and a challenging task at the design stage.

*4.2.3 Commercial installation considerations*

For commercial installation, night-time operation usually drives the acoustic design due to lower environmental background sound levels. Although buildings may only be occupied during daytime hours, frost protection operation or building pre-heating may occur during normally quiet periods of the night. The cumulative impact of multiple units may need appropriate assessment.

*4.2.4 Rating level thresholds*

Currently local authorities take various approaches to setting sound impact limits relative to background sound levels: some permit rating levels 5 dB above background, while others require the rating level to be 10 dB below background, although meeting the background sound level is more common. The more stringent limits are likely to be a significant obstacle to the roll-out of ASHPs.

## 5. PRAGMATIC APPLICATION OF ASSESSMENT METHODS

We propose a hierarchical, risk-based framework for assessment that could streamline the planning process while maintaining acoustic protection. A standardised, industry-accepted approach could itself reduce costs and risks associated with proposed installations.

### 5.1 Step 1: Enable a fixed level threshold for planning

Where an installation requiring planning permission can demonstrate compliance with the 37 dBA threshold from MCS 020, this could be considered sufficient evidence of acceptable acoustic impact. This approach could significantly reduce assessment costs for domestic installations that fall outside permitted development, as well as non-domestic installations that are low-risk due to the low sound level impact. The approach of using fixed threshold levels is proven to be successful across Scotland and much of Europe, where daytime thresholds are generally significantly higher than 37 dBA.

### 5.2 Step 2: Allow the MCS 020 sound propagation model

To minimise the cost of the acoustic assessment, the simplest assessment of sound transmission is embodied in the MCS 020 sound transmission model. Where an assessment uses the MCS 020 sound transmission model and threshold, it is compliant with PDR requirements. Although there is currently nothing preventing planning authorities from approving this method for planning applications, it could be positively affirmed as being sufficient, given its demonstrated prudence in comparison with more detailing sound propagation modelling.

### 5.3 Step 3: Permit more detailed sound propagation assessment

Where a simple sound transmission model indicates a marginal failure to comply with the identified criterion, permitting more detailed modelling of sound propagation would be appropriate. However, there are a variety of models, and many model parameters that practitioners may consider to various extents. It is suggested that industry-standard guidelines for modelling ASHP sound propagation with ISO 9613-2 are developed by consensus, to help achieve consistency.

This route could avoid the additional resources associated with a background sound survey while benefiting from more sophisticated treatment of barriers and reflecting surfaces.

### 5.4 Step 4: Predetermine higher thresholds in higher background sound environments

Where background sound levels are higher, it can be unnecessary to mitigate the sound impact to the threshold level that is considered suitable everywhere – i.e. a higher impact can be acceptable according to BS 4142.

A consensus on rating level margins could expedite assessments and reduce risks and delays with a process of agreeing rating level thresholds compared with background sound levels on a case-by-case basis, as can happen currently.

A BS 4142 assessment also requires an assessment of tonality, intermittency, impulsiveness, and any other features that may attract a rating penalty. In the absence of this information at design stage, a consensus could be developed to agree rating penalties for these features.

### 5.5 Step 5: Full BS 4142 assessment

Beyond the features of step 4, a full BS 4142 assessment also includes consideration of context, on a case by case basis. Although practitioners regularly carrying out these assessments, there is no assurance of consistency; consultants working for developers and public protection officers may take different views of appropriate penalties between each other as well as amongst themselves. This is the current state for all assessments that fall outside the scope of MCS 020 and PDR.

## 6. FURTHER OPPORTUNITIES TO FACILITATE ASHP ROLLOUT, AND FURTHER WORK

### 6.1 Enable further acoustic assessment options under PDR

The first four steps of assessment could be adopted in MCS 020. This could enable some of those properties that currently marginally fail the "noise test" (i.e. just fail to comply with the current scope of MCS 020) to benefit from a more detailed acoustic evaluation, while still avoiding a full planning application. A more detailed assessment would need to be undertaken by a suitably competent person; while MCS 020 is designed to be undertaken by an installer with no specialist acoustics knowledge, a more nuanced a sophisticated assessment would require commensurate accountability, which would be based on a greater level of expertise and experience. It would be prudent to investigate the real-world evidence base discussed below first, to help establish the case for this option.

### 6.2 Extend PDR

Currently PDR apply to domestic installations only, where there may be a maximum of two units per dwelling. Permitted development rights could be extended to non-domestic properties, with prior approval being required if necessary as a safeguard against potential adverse effects from cumulative impact, for example. This could reduce the planning barriers to ASHP uptake.

### 6.3 Daytime / Night-time thresholds

The single threshold in the UK that applies at all times of day and night is similar to the nighttime limit in other European countries, where a higher daytime limit is also used. It is standard practice in some European countries to design to different daytime and nighttime sound level thresholds, and to use a reduced sound power mode at night if this is necessary for acoustic compliance.
Discussions with installers during recent research indicated little appetite for this approach, in part amid concerns that residents may adjust the settings on their appliances. Currently installers need not waste time with sites that present challenges, but for wider roll out the more acoustically challenging sites will also need solutions. Enabling higher sound levels during the daytime is one option that could facilitate installations for sites that might otherwise be problematic, and accepting quiet mode operation with associated drop in thermal performance at nighttime.

### 6.4 Real world evidence base

Currently there appear to be relatively few noise complaints compared with the numbers of installations. However, there is little information about real-world sound impact from installations that are designed with the MCS 020 method. Building further confidence in this approach, and considering potential changes to the threshold levels requires systematic post-installation studies comparing predicted and measured levels, alongside documentation of planning outcomes where MCS compliance has been used as evidence.
Field measurements comparing predicted and actual sound levels are needed to validate both MCS 020 and ISO 9613 predictions. These studies should also examine real installations across different mounting arrangements, particularly investigating the effectiveness of different barriers and the influence of reflecting planes, and the potential effectiveness of sound absorption on nearby surfaces. This also requires a methodology for measuring the sound of an ASHP installation in-situ, which is not a simple task.
This evidence base would help to determine if the current threshold is appropriate, too permissive or too restrictive, and could support a future revision.

### 6.5 Cumulative impact considerations

Previous research [17] has investigated the potential for cumulative sound impact from multiple domestic ASHPs in high-density residential areas. The study focused on worst-case scenarios in terraced and semi-detached housing, representing the majority of the UK's housing stock. Even under conservative assumptions with all units operating simultaneously at maximum permissible MCS sound levels, the increase in overall sound levels was found to be modest. The cumulative effect typically resulted in increases of up to 2-3 dB at dwelling facades compared to a single unit, with larger increases occurring in garden areas and places where absolute levels remained low.
These findings have important implications for our proposed assessment framework. Where a Step 1 assessment demonstrates compliance for individual installations, cumulative impact is unlikely to be significant even in high-density deployments. Therefore planning conditions requiring the impact to be many decibels below the background, to prevent cumulative impact, are considered unnecessary, and could hinder the roll-out of ASHPs.

## 7. CONCLUSIONS

The evidence presented strongly supports adopting a proportionate framework for ASHP acoustic assessment. Using MCS 020 as an initial screening tool, with options for detailed modelling in borderline cases, or assessment against a higher background sound level, could significantly reduce obstacles to installation while maintaining appropriate acoustic protection. Success relies on planning authorities agreeing clear guidance on:

- Criteria for selecting appropriate assessment steps
- Documentation requirements proportionate to installation complexity
- Treatment of cumulative impacts
- Standardised approaches to character corrections where detailed data is unavailable

The evidence from the further work proposed would help refine assessment methodologies and support wider adoption of ASHPs whilst maintaining appropriate acoustic protection. This is particularly important as the scale of heat pump deployment increases to meet decarbonisation targets. Implementing this risk-based framework would remove unnecessary barriers to heat pump adoption while ensuring communities remain protected from inappropriate noise impacts.

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