PLANNING FOR SOUND FROM ASHPS: OPTIONS, RISKS AND OPPORTUNITIES

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ABSTRACT

Air source heat pumps (ASHPs) play a crucial role in decarbonising heating, but their widespread adoption necessitates addressing potential sound impacts. This paper critically examines the planning and assessment methodologies for ASHP sound emissions from domestic installations, focusing on the Microgeneration Certification Scheme (MCS) 020 standard and its comparison with acoustic modelling to BS ISO 9613-2. Through comprehensive acoustic modelling of realistic scenarios, we demonstrate that the MCS 020 method consistently predicts higher sound impact levels compared to ISO 9613-2, often by 5-7 dB. This discrepancy is attributed to differences in treating reflective surfaces and barrier attenuation. Our findings suggest that MCS 020, while designed for permitted development, is prudent to use for planning purposes; however, it may be overly restrictive in many cases where the sound does not have tonal characteristics. We propose updates to MCS 020, including refined distance calculations and treatment of reflective surfaces. Additionally, we recommend introducing an option for more detailed acoustic modelling using ISO 9613-2 within the MCS framework. This approach could help avoid the planning process for borderline sound cases while maintaining adequate sound protection. We outline critical areas for further research, including advanced modelling techniques and real-world installation studies, to inform future standards and ensure a suitable balance between facilitating ASHP adoption and community sound management.

1 INTRODUCTION

In the imperative to decarbonise heating, Air Source Heat Pumps (ASHPs) are a key technology. However, the successful integration of ASHPs hinges on addressing concerns regarding their sound emissions, and its impact on their neighbours and the occupants themselves. This paper discusses the multifaceted landscape of planning for ASHP sound impacts from domestic installations. We critically examine the strengths and weaknesses of existing assessment methodologies, contrasting the use of the MCS 020 sound standard [1] with the BS 4142 framework for planning applications. We compare the MCS sound propagation model with ISO 9613 for real sample ASHP units.

Our modelling indicates that the ISO 9613 model predicts a lower sound impact compared to MCS 020 in all of the scenarios considered here. This observation underscores the potential of MCS 020 to serve as a 'worst-case' scenario assessment, fostering confidence in its adoption for planning purposes, or providing a margin of error to allow for aspects that may also be captured in more complex assessments such as sound character (e.g. tonality or low frequency sound). The inherent simplicity of applying MCS 020, in contrast to the complexities and costs of completing an assessment to BS 4142, positions it as a pragmatic choice for deployment in planning applications.

We elaborate on the nuances of ASHP sound characteristics, explore ambiguities within laboratory sound power level characterisation, and draw upon international perspectives to contextualise our findings. By offering clarity on these critical issues, we aspire to empower effective planning and regulation of ASHP sound impacts, ensuring a harmonious balance between the urgent need for decarbonisation and the imperative to minimise acoustic disturbance to residents.

The MCS 020 sound standard is based on simplified assumptions about ASHP source sound emissions, a simplified sound propagation model, and a sound level threshold for compliance. When considering the MCS 020 standard, all these aspects must be considered together. The MCS 020 standard has been considered in some recent reviews of suitability for Permitted Development Rights [2, 3, 4]; however, its use as a standard for planning has not been addressed.

2 CONSIDERATIONS FOR ACOUSTIC PLANNING

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

- Characterisation of the sound source
- A sound propagation model
- A method for assessing the impact

These aspects are considered in turn.

2.1 Characterisation of the sound source

To comply with European Directive 813/2013 [4], 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 [4]. 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” sound power, such as in the German Heat Pump Association’s online calculator [5], as illustrated in Figure 1. A sample of data is presented in Figure 2, which illustrates that the maximum sound power may be up to 15 dB more than the ErP sound power, or it may have the same value. Figure 2 shows that at lower sound power levels, below 60 dBA, the maximum sound power diverges more significantly from the ErP sound power.

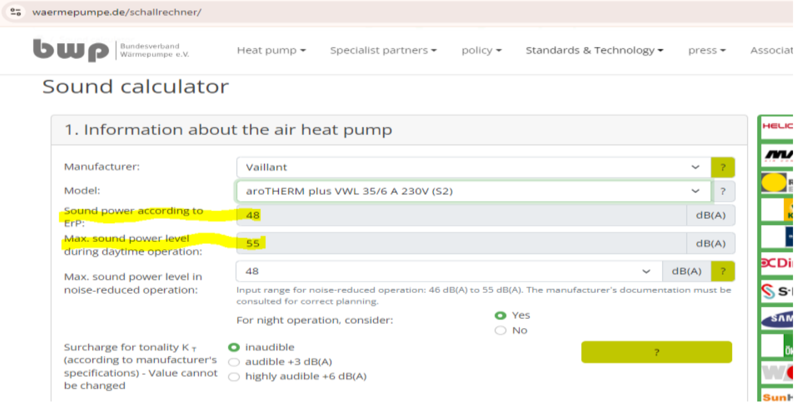


Figure 1: Illustration of the German Heat Pump Assoc. online calculator, with a sample unit selected

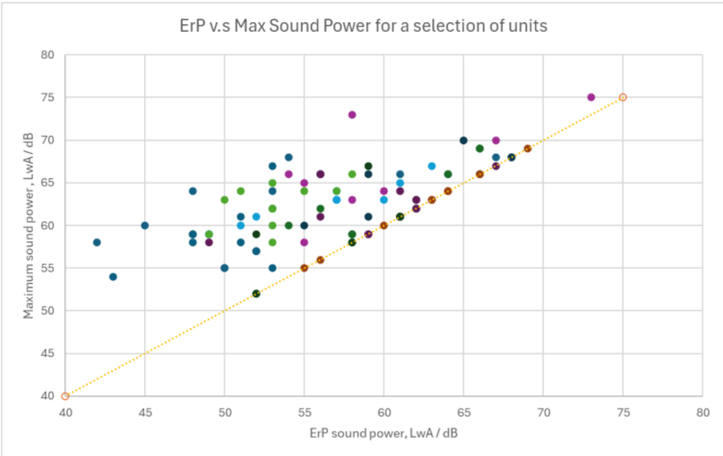


Figure 2: ErP vs Maximum sound power for a sample of units on the German Heat Pump Association website. Colours represent different manufacturers.

In practice, the sound power emitted may vary considerably over time based on environmental conditions, the installation design, and the control strategy. A seasonal sound power characteristic has been proposed [8], to describe an average annual sound emission.

The specification for the sound power test includes the reporting of sound power in third octave bands. However, this information is not usually available from suppliers in the UK. Some countries include a penalty for tonality in the assessment at design stage, as can be seen in the German heat pump association. The information on the German website indicates a “surcharge” (penalty) for tonality, K_T. The accompanying information notes:

A.2.5.2

Surcharge for sound and information content K_T

For the partial periods in which one or more tones are prominent in the noise emissions to be assessed or in which the noise contains information, the value K_T shall be set at 3 or 6 dB, depending on the degree of conspicuity.

For systems whose noise does not contain tonal or informational content, K_T = 0 dB.

If experience from comparable systems and system components is available, these should be taken into account.

A.3.3.5 Surcharge for sound and information content

If one or more tones are audibly prominent in a noise during certain partial times T_j or if the noise contains information, the premium for tonal and information content $K_{T,j}$ for these partial times is 3 or 6 dB, depending on the conspicuity. The tonal quality of a sound can also be determined by measurement (DIN 45681, draft edition May 1992).

Note that DIN 45681 [6] can only be applied in-situ for the determination of tones, i.e. not in advance at the design stage. It is not clear how the values for K_T in the German database have been determined; random sampling of manufacturers and models has not revealed any units that have a K_T penalty.

There is no standardised information available from suppliers in the UK that indicates tonality of the source sound. It has been mentioned previously [2] that including a characterisation for tonality may facilitate consistency in assessments, but this information is not currently available.

Low frequency sound (below the 100 Hz third octave band) is not measured according to the standards - laboratories are generally not big enough to do so in a statistically reliable way, and directional characteristics are also not measured. There is only one facility in the UK for measuring the sound power of ASHPs, at BSRIA. This requires 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.

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. This either introduces a risk that designers cannot mitigate, or they do so by adopting a prudent approach and assuming that all units are tonal and attract a penalty. This approach potentially hinders the rollout of ASHPs unnecessarily, as it can entail an unnecessary constraint where there are little or low levels of sound character.

2.2 Sound propagation modelling

2.2.1 MCS 020 sound propagation model

As MCS 020 requires application by non-acousticians, it is based on three simple input data. These are the:

- Distance between source and assessment position, rounded down to tabulated integer values
- No. of reflecting planes, either one, two or three;
- Barrier attenuation, either 5 or 10 dB

These data are used to calculate the sound propagation to the receptor location. Knowledge of the source sound power enables determination of a level at the assessment position. The approach is a simplified version of the same concept in ISO 9613 for geometric spreading of sound with distance, although the barrier attenuation in MCS 020 is much simpler and applied in a stepwise manner. The effect of “reflecting planes” in MCS 020 is distinctly different from reflecting surfaces in ISO 9613. In MCS 020, a reflecting plane conceptually constraints the sound propagation to half the previously available space, such that each subsequent reflecting plane that is present ads 3 dB to the calculated level at the receptor. In ISO 9613, reflecting surfaces enable an additional sound propagation path for those rays that have a specular reflection to the receiver location.

2.2.2 ISO 9613-2: 2024

The method recommended in BS 4142 for calculating sound propagation outdoors is BS ISO 9613-2 [7]. This model can only practically be applied using specialist software, although the basic components for simple geometric arrangements can be calculated by hand. Whilst the model can accommodate directional information about a sound source, this information is not generally available for ASHPs.

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 primarily focuses on sound propagation over longer distances and in open environments, which may not accurately reflect the close proximity and complex geometries often encountered in ASHP installations. The standard's assumptions about ground effects and meteorological conditions might also not be entirely suitable for the micro-scale environments where ASHPs are typically located. ISO 9613 does not include wave-based sound propagation effects on tonal content, which can influence the perceived impact.

2.2.3 Boundary Element Method

The Boundary Element Method (BEM) is a numerical computational technique used to solve complex engineering and physical problems, including those in acoustics. It's particularly well-suited for scenarios involving sound propagation in complex geometries, where analytical solutions are often impractical or impossible. It is not used by consultants in general, it is more the preserve of specialist academics. BEM can offer several advantages over empirical methods like MCS 020 or even ISO 9613-2 for modelling ASHP scenarios. It can accurately account for the intricate interactions of sound waves with various surfaces, including reflections, diffractions, and scattering. This may be important in situations where ASHPs are installed in confined spaces or near multiple reflecting surfaces. While BEM offers greater accuracy and flexibility, it also requires more computational resources and expertise compared to simpler methods.

2.3 Sound impact assessment

With a characterisation of the sound source and a sound propagation model, a sound impact is calculated that is typically evaluated against a limit to determine an acceptable or unacceptable situation. The MCS 020 standard has a fixed absolute limit of 37 dBA based on the declared ASHP sound power level, which disregards tonality, low frequency sound, and any intermittency of the sound source during different phases of operation (e.g. during defrosting).

The default method for Planning is to use BS 4142 [9] to evaluate and assess the significance of the impact. It is based on the sound at the receptor location, there is no sound propagation model in BS 4142. The sound impact is rated by adding penalties for sound characteristics such as being intermittent, impulsive, tonal or having character features; the rating level is compared with the background sound level, and the assessment takes account of the context. The context can include the absolute levels of the specific source of sound and the background level, and other aspects of the particular environment.

Although BS 4142 does have methods for rating sound features, laboratory tests for ASHPs do not currently measure or evaluate these characteristics. Hence unless the practitioner has knowledge and extensive measurements of an equivalent operational unit to that proposed, it is not possible to rate the potential sound impact according to BS 4142 in this way. In these situations practitioners sometimes apply a penalty as a matter of prudence; however, this could provide an obstacle to ASHP installations that may be unnecessary. The title of BS 4142 should also be recalled, which is “Methods for rating and assessing industrial and commercial sound”. A domestic ASHP installation is not industrial or commercial sound, and therefore it could strictly be considered to be outside the scope of BS 4142.

3 MODEL BENCHMARKING MCS 020 WITH ISO 9613

3.1 Modelling introduction

A modelling exercise is presented to compare the MCS 020 (“MCS”) sound propagation model with that in ISO 9613-2 (“ISO”). The modelling compares the calculated impact, and implications for barriers, based on currently-available ASHPs. The sources of the sample ASHPs and physical environment are summarised in **Table 1**.

Table 1: summary of choices for modelling attributes

Model attribute	***Comments***
Housing typology	*Sample “worst case” housing was selected based on typical housing developments, where the upstairs windows are close to the party wall. These are small two storey houses that may be terraced or semi-detached, approx. 75 m2.*
Sample ASHP	*Sample monobloc units were selected from four random popular manufacturers according to the MCS database.*
Barrier heights	*Based on the real ASHP unit dimensions, manufacturer’s clearances and sound power level, the barrier height required to comply with the MCS is calculated.*
Modelling to ISO 9613 using CadnaA	*Each scenario was modelled using CadnaA software. The ASHP was represented in three distinct ways:* • *a floating point source at the top of the unit* • *a floating point source at the centre of the unit* • *an area source on top of a box representing the unit* *Model calculation settings include:* *All surfaces have 1 dB attenuation, equivalent to absorption coefficient of 0.21* *G = 0* *Number of reflections = 3* *Surfaces less than 1 m from the source or receiver ARE included for reflections*

The results from the MCS and ISO models are compared, to review differences and potential implications for planning and assessment practices. It should be noted that neither method is “more correct”. In-situ sound emission levels and validation of sound propagation models is a separate question that goes beyond the scope of this paper.

3.2 Selection of worst case housing typology

It can be seen from Figure 5 that the location of the top left hand corner of the ASHP is critical in determining the barrier height required to achieve 5 or 10 dB in the MCS model. It is therefore vital to consider a representative range of realistic geometries. The Nationally Described Space Standard (NDSS) [10] describe minumum areas, but not minimum dwelling widths, as shown in Figure 3

Number of bedrooms (b)	Number of bed spaces (persons)	1 storey dwellings	2 storey dwellings	3 storey dwellings
1b	1p	39 (37) *		
1b	2p	50	58	
2b	3p	61	70	
2b	4p	70	79	
3b	4p	74	84	90

Figure 3: Extract of Nationally Described Space Standards for the smallest dwellings

It can be seen from Figure 3 that the smallest two storey dwellings could be 1 bed 2 person (“1b2p”). A range of typical modern dwelling designs complying with the NDSS has been reviewed, wherein the smallest 2 storey dwellings commonly found in practice are 2b3p, which has a minimum floor area of 70 m^2. In the dwellings reviewed, those just meeting the 70 m^2 requirement have a single, centrally located window for each of the bedrooms, one at the front and one at the rear of the property. In the designs reviewed, a 2b3p design at 75 m^2 has two windows on the rear elevation, meaning that an assessment position is much closer to the neighbour’s ASHP. This worst case design is therefore selected for the following analysis, as illustrated schematically in Figure 4.

3.3 Sample ASHP selection

We understand that modern housing may need a heating capacity of around 30 W/m^2. As these houses have floor areas around 75 m^2, an ASHP unit of 3 kW or more is sufficient. Monobloc units of around this size from four leading UK suppliers according to the MCS database were selected for inclusion.

3.4 ASHP assessment positions and geometry

The first sample ASHP location considered is adjacent to the boundary fence. At the time of writing, Permitted Development Rights (PDR) in England require a minimum distance of 1 m from the ASHP to the boundary. Following the consultation in 2024, it is anticipated that this constraint is likely to be removed in future, so that ASHPs can be located closer than 1 m to the property boundary. For the purposes of a planning application this is not a constraint. As is demonstrated below, it is important that the ASHP is located less than 1 m from the property boundary, to enable the boundary fence to act as a sound barrier.

Figure 4 illustrates the ASHP location and the assessment positions considered. These are:

- Position 1 - Adjacent house, First Floor window (FF Adj)
- Position 2 - Adjacent house, Ground Floor patio doors (GF Adj)
- Position 3 - Opposite side house, First Floor window (FF Opp)

These positions are each the worst affected positions for each of the anticipated barrier attenuations of 0, 5 and 10 dB, for positions 3, 1, and 2 respectively. In accordance with MCS, the assessment positions are 1 m in front of the centre of the windows or doors to habitable rooms. In Figure 4, the ASHP is illustrated with its back to the house. Figure 5 illustrates schematically the minimum barrier heights to achieve 5 and 10 dB attenuation in the MCS 020 model.

Figure 4: Schematic of ASHP location and the three assessment positions numbered

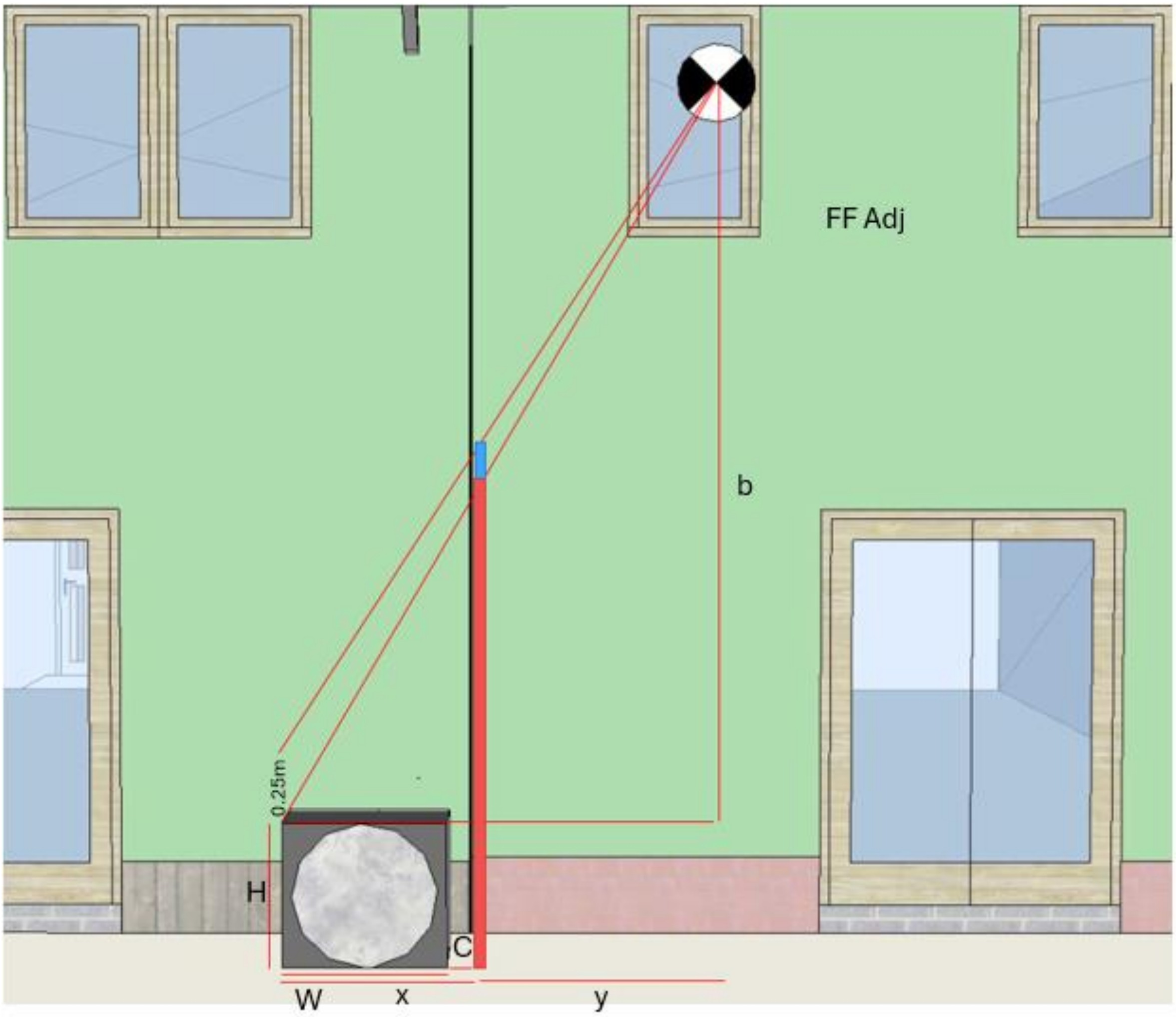


Figure 5: Illustration of calculation of minimum barrier heights to qualify for 5 or 10 dB attenuation in the MCS model.

The minimum heights to qualify for a barrier providing 5 or 10 dB are given by the following formulae.

Minimum height for a 5 dB barrier (m) = $H + (x * \frac{b}{(x+y)})$

Minimum height for a 10 dB barrier (m) = $H + 0.25 + (x * \frac{(b-0.25)}{(x+y)})$

Where: W, H are the Width and Height of the unit respectively;

C is the Clearance required according to manufacturer's specifications

X is the Width of ASHP plus Clearance (W + C)

Y is the horizontal distance from barrier to centre of window

b is height of the centre point of the window minus H

3.5 Sample ASHP unit dimensions and sound power

Table 2 shows the real unit dimensions, minimum clearances and the sound power level of the sample units selected for this modelling exercise, taken from manufacturers' literature.

Table 2: Sample unit dimensions, clearances and sound power

Sample unit #	***Unit dimensions / m***			***Minimum clearances / m***			***Sound power / dBA***
	w	*d*	*h*	*Left*	*Right*	*Rear*	
A	*0.81*	*0.32*	*0.72*	*0.1*	*0.1*	*0.3*	*53*
B	*0.82*	*0.29*	*0.62*	*0.1*	*0.3*	*0.1*	*55*
C	*1.1*	*0.45*	*0.77*	*0.1*	*0.5*	*0.25*	*54*
D	*1.25*	*0.36*	*0.77*	*0.25*	*0.5*	*0.3*	*58*

3.6 Calculating barrier height required

Based on the distances calculated and the lookup table from MCS 020 reproduced in Figure 6, the resultant sound levels or sound power limits for a given distance are calculated.

Q (STEP 2 RESULT)	Distance from Heat Pump (metres) (STEP 3 RESULT)													
	1	1.5	2	3	4	5	6	8	10	12	15	20	25	30
2	-8	-11	-14	-17	-20	-21	-23	-26	-28	-29	-31	-34	-36	-37
4	-5	-8	-11	-14	-17	-19	-20	-23	-25	-26	-28	-31	-33	-34
8	-2	-5	-8	-11	-14	-16	-17	-20	-22	-23	-25	-28	-30	-31

Figure 6: look-up table for distance attenuation as a function of Q-value

The MCS requirement can be written simply as shown in Equation 1.

$L_p = L_w$ + Dist. Attenuation + Barrier attenuation   Eqn 1

Where L_w = ASHP sound power level

Dist. Attenuation is from Figure 6

Barrier attenuation is either 0, 5 or 10 dB, following the MCS description

To comply with the MCS requirement,, $L_p <= 37$. There are no decimal points in calculations to the MCS standard. Hence using the MCS, for a given ASHP sound power, L_w, in a given situation where distance and Q are evident, it is simple to determine if a barrier is required

4 RESULTS

4.1 ASHP located back to the house

With the ASHP located with its back to the house, positioned as close as possible to the boundary fence to act as a sound barrier, the distance from the geometric centre of the unit to the adjacent first floor window (FF Adj) assessment position is calculated to be more than 4 m, and less than 5 m, as shown in Table 3. Similarly, to the adjacent ground floor, where there is a central patio door, the distance is also shown in Table 3, as is the distance to the first floor window on the opposite side (FF Opp). As the ASHP is within 1 m of the ground, the house facade and the boundary fence, a value of Q = 8 is used in the MCS model. These distances, Q factor and the sound power levels given in Table 2 mean that in all these cases, a barrier to the adjacent house is required that provides at least 5 dB attenuation to the FF Adj (one ASHP requires a 10 dB barrier), and 10 dB attenuation to the GF Adj assessment locations. The minimum height of this barrier is shown in Table 3.

Table 3: MCS assessment data for ASHP back to house

Sample unit #	***Dist. to assessment position / m***			***Barrier height required / m***
	1- FF Adj	*2- GF Adj*	*3- FF Opp*	
A	*4.3*	*3.2*	*7.1*	*2.3*
B	*4.4*	*3.4*	*7.0*	*2.4*
C	*4.5*	*3.7*	*6.7*	*2.8*
D	*4.5*	*3.8*	*6.8*	*3.0******

* Requires 10 dB barrier attenuation due to the unit SWL at this distance.

While barrier heights above 2.0 m are unlikely to be preferred, It is suggested that barrier heights above 2.4 m are unlikely to be acceptable. Moreover, with the current MCS calculation, there is no difference in distance attenuation between 6 and 8 m, from the look-up table, as shown in Figure 6.

Based on a distance of 6 m, with Q = 8, and no barrier, the MCS 020 calculation indicates a maximum sound power of 54 dBA. Therefore two of these sample units would fail the MCS test not to the adjacent dwelling, but to the one on the opposite side, where there is no sound barrier between the unit and assessment location 3. It can be seen that potential compliance with the MCS standard is a function not just of sound power, but the unit dimensions also determine the barrier height required, which can also be prohibitive. It is important to remember that The MCS standard takes no account of the impact of sound on the garden or on the occupants' internal environment, but focuses on the protection of the habitable rooms of the neighbouring property.

4.2 ASHP located back to the fence

To reduce the required barrier height, it is necessary to move the position that drives the barrier height closer to the barrier. As all the units have a (width + side clearance) that is greater than (depth + rear clearance), the units can be tucked in behind the barrier more effectively if they are located with their back to the fence, rather than to the house. This means turning the unit through 90 degrees, to face across the facade of the house to which it belongs, as illustrated in Figure 7. This moves the top left corner of the unit (when looking at the facade) that determines the barrier height slightly closer to the boundary fence. This means that the barrier does not need to be as high to qualify for the 5 dB attenuation. With this arrangement, the minimum barrier heights required to achieve the minimum 5 dB barrier to assessment position 1 is shown in Table 4. For sample ASHP unit 4, the barrier is required to provide 10 dB attenuation due to the source sound power level, and thus the height indicated is to qualify as a 10 dB barrier.

Figure 7: illustration of the ASHP unit arranged with its back to the fence, with a taller barrier portion (here shown at 2.0 m), extending 2 m from the house only, with the remaining fence shown at 1.8

Table 4: MCS assessment data for ASHP back to boundary fence

Sample unit #	*Dist. to assessment position / m*			*Barrier height required / m*
	FF Adj	*GF Adj*	*FF Opp*	
A	*4.3*	*3.2*	*7.2*	*2.0*
B	*4.2*	*3.0*	*7.4*	*1.5*
C	*4.2*	*3.2*	*7.1*	*2.1*
D	*4.2*	*3.2*	*7.1*	*2.2**

* Requires 10 dB barrier attenuation due to the unit SWL at this distance.

The barrier heights presented in Table 4 are more likely to be acceptable, but may still be higher than preferred. Although the distances between ASHP and assessment locations all change slightly, they do not change the distance attenuation attributed with the MCS, as the values remain between the same relevant integer steps for distance attenuation shown in Figure 6. It is worth noting that if the distance attenuation were calculated accurately from the theoretical equation on which it is based, unit C would PASS the MCS test to the opposite FF window, and would therefore also be a compliant unit.

Note that for Sample D, due to the higher sound power, a 10 dB barrier is required to assessment position 1, leading to the higher barrier heights compared to the other units. It is important to note that the barrier heights are also driven by the distance from the property boundary to the centre of the first floor window on the adjacent property, denoted with the symbol *y* in Figure 5. Figure 8 shows how the minimum barrier height to qualify for a 5 dB or a 10 dB barrier in the MCS calculation varies with this distance, y metres. This sample dwelling is 5.2 m in width, therefore if it only has a single central window, the distance from the property boundary would be 2.6 m. The values in Figure 8 are derived from ASHP sample unit A placed with its back to the house; these dimensions vary if it was placed back to the fence. Note that different sized units with different clearance specifications will have a different relation between distance, y, and the minimum barrier heights. The relation shown is only valid for ASHP sample A.

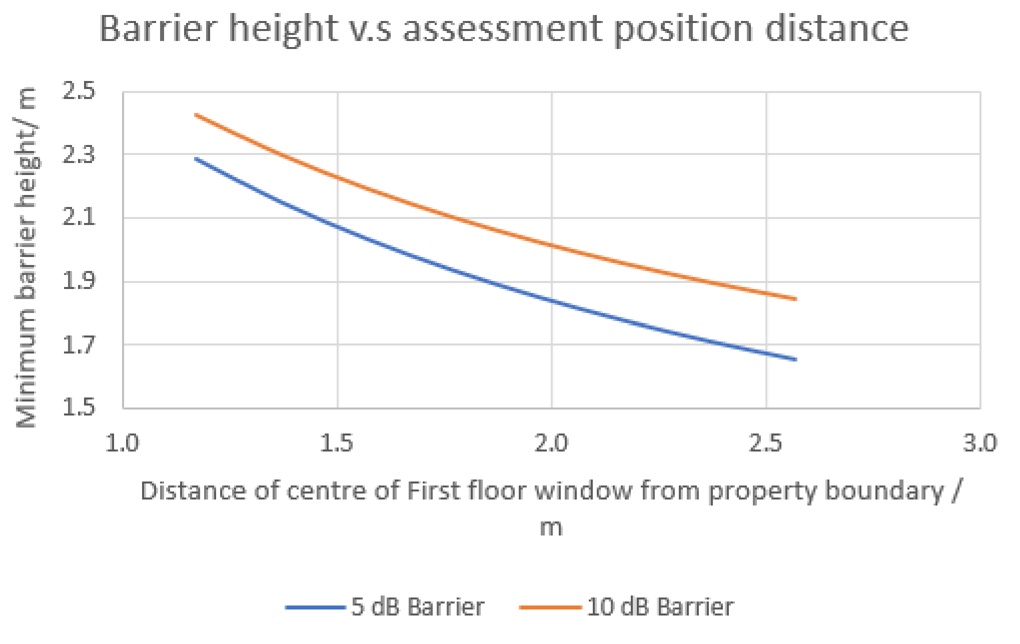


Figure 8: variation of barrier height with distance of assessment position 1 (FF Adj) from the property boundary, for ASHP sample unit A.

4.3 Comparison of MCS 020 results and ISO 9613 model

A range of models with variants of the relevant constraints is presented, to illustrate how the MCS model compares with the ISO model, using CadnaA software [11]. Three different ISO model configurations of the source are considered in each scenario, with the sound source characterised either as a point source or an area source. The point source is located either at the location of the:

- Centre of the top face of the ASHP box dimensions (described as “PT” for “Point Top”), or the
- Geometric centre of the box dimensions (“PM” for “Point Middle”).

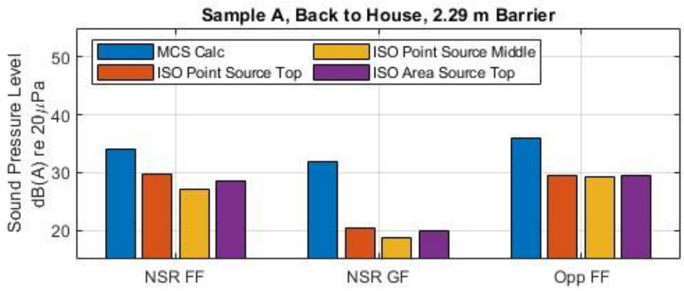
When a point source is used, the ASHP “box” is omitted.

When an area source is used, it is applied to the:

- Top surface of the ASHP box (“AT” for “Area Top”)

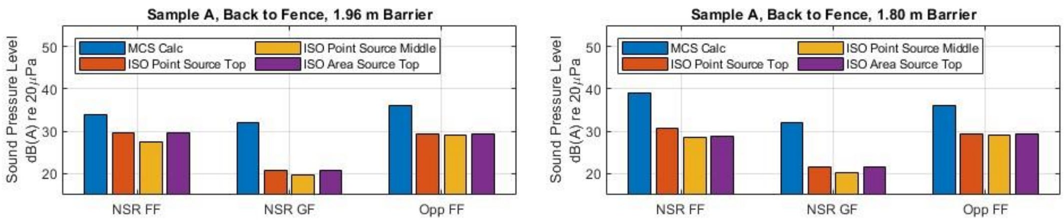
All these configurations are considered potentially appropriate ways to model the sound source, depending on the physical context. When compared with the MCS calculation, this means that there are four results for each scenario. Where the barrier height required is more than 2.0 m, according to the MCS calculation, a further scenario is undertaken with a barrier at 1.8 m high. Although this is non-compliant with the MCS standard, the variation of results between ISO and MCS models is of note. The full results are presented numerically in Appendix A, with a sample of selected graphical representations below.

4.3.1 Sample A, back to house



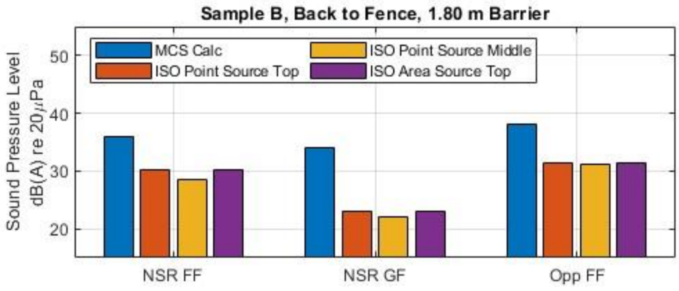
With this 2.3 m barrier, at assessment position 1 the ISO results in an impact between 27 dB (PM) and 30 dB (PT), where the MCS result is 34 dBA. Also worth noting that at assessment position 2, the GF Adj location, the MCS calculation includes a 10 dB barrier attenuation to determine an impact of 32 dB, whereas the ISO model indicates values between 19 and 20 dB, i.e. a greater extent below the MCS result. At assessment position 3, MCS calculates 36 dB, whereas ISO calculates 29 dB for all configurations.

4.3.2 Sample A, back to fence



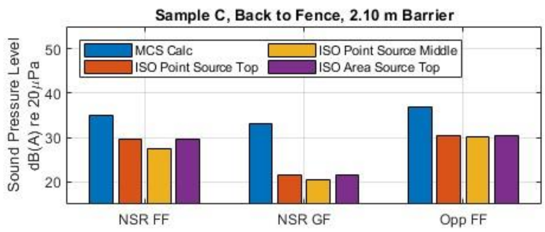
With Sample A placed back to the fence, with two different fence heights, the differences between these scenarios in the ISO models are small, but the difference in the MCS calculation is 5 dB at assessment position 1, from 34 to 39 dB. The ISO model calculates a difference of 1 dB for all source configurations.

4.3.3 Sample B, back to fence



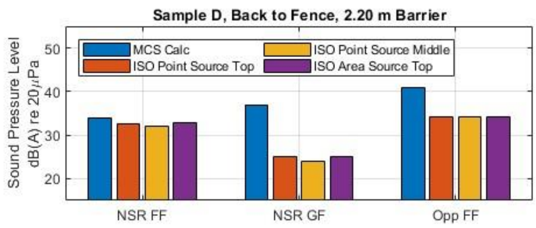
Due to the dimensions of this ASHP sample unit, the required barrier height is only 1.54 m to qualify for the MCS 5 dB barrier attenuation. The model is carried out with a barrier height of 1.8 m. At assessment position 1, levels vary between 24 and 30 dBA in the ISO model, compared with 36 dB for the MCS model. The MCS model indicates 38 dBA at assessment location 3, which fails to meet the 37 dBA threshold. If the attenuation in the MCS model was calculated to the nearest 0.1 m, this would meet the MCS threshold at position 3. The ISO models all calculate 31 dB at position 3.

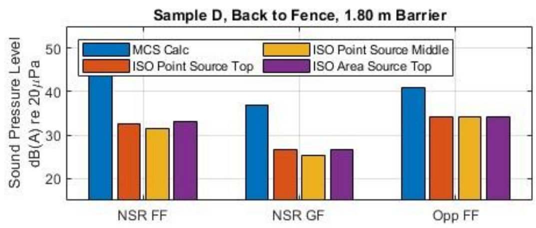
4.3.4 Sample C, back to fence



Sample C is on the upper limit for compliance at assessment position 3, and requires a 2.1 m barrier to comply at position 1, where the ISO model calculates between 28 and 30 dB with a 2.1 m barrier, and between 29 and 32 dB with a 1.8 m barrier, compared with 40 dB in the MCS model.

4.3.5 Sample D, back to fence





Sample D fails to meet the MCS 020 threshold at assessment position 3, where the calculated result is 41 dBA. This unit would still fail to meet the 37 dBA threshold if the actual distance of 7.1 m was used to determine distance attenuation; the current MCS method requires a distance of 6 m to be used where the measured distance is between 6 and 8 m.

The change in barrier height from 2.2 to 1.8 m means that the MCS calculation changes by 10 dB at assessment position 1, whereas the change in the ISO model is less than 1 dB for all modelling configurations between the different barrier heights. This illustrates how significant the step changes are in the MCS model compared with the ISO model.

5 DISCUSSION

5.1 MCS model consistently predicts significantly higher results

The most striking aspect of the results is the extent to which the MCS model consistently calculates higher values of sound impact compared with the ISO model. This can be understood as the cumulative contribution from two discrete factors, the Q-factor and the barrier attenuation.

5.1.1 Q-factor in MCS calculation

All the models presented here use Q = 8 (three reflecting planes), which adds 6 dB to the calculated result compared with Q = 2 (one reflecting plane). As we are using the ISO model with G = 0, this has the same effect as Q = 2, in that it increases the calculated level by 3 dB compared with sound propagation from a point source in space without any reflections. But beyond this first surface, the MCS model and the ISO model treat reflecting planes or surfaces very differently. The ISO model calculates much smaller increases in sound levels when additional reflective surfaces are added in close proximity to the sound source (despite our taking care in the model to include reflections from surfaces less than 1 m from source and receiver locations, which is the default distance setting to exclude reflections).

Although a sound barrier fulfils the description of a reflecting plane in the MCS model, and therefore should be included in determining the Q factor, it does not make conceptual sense as we are interested in the sound level beyond the barrier. The assumption of a reflecting plane effectively treats the propagation as if all the sound energy is constrained by the reflecting plane: clearly these are incompatible concepts. If the sound barrier is discounted as a reflecting plane, the MCS calculation indicates a level 3 dB lower. This would make the MCS calculated levels more commensurate with those from the MCS model.

5.1.2 Barrier attenuation

The barrier attenuation attributed in the MCS model is generally significantly lower than that calculated in the ISO model. The most significant constraint of the MCS barrier calculation is the way in which it is defined geometrically, which results in barrier heights for the samples modelled here that are disproportionately tall to the power of the sample units and geometry of the houses. The MCS models for samples A, B, and C all fail to meet the 37 dB criterion, without a barrier, by less than 3 dB at assessment position 1. Thus no barrier attenuation is required to this position if the barrier (boundary fence) does not constitute a reflecting plane, and the Q-factor is reduced to a value of 4. The ISO models all indicate that a lower barrier at 1.8 m is adequate to sufficiently mitigate sound to meet the MCS criterion for these sample ASHPs. ASHP sample 4 has a slightly higher sound power level; even with Q=4, this sample still requires some barrier attenuation to comply at position 1.

5.1.3 Differences at assessment position 1

Where the assessment position is horizontally close to the ASHP location, as in the scenarios considered here, it is shown that the required barrier height to qualify for a 5 dB attenuation in the MCS model is very sensitive to the particular location from which the requirement is defined. Figure 8 illustrates how the required barrier height becomes practically feasible when a small ASHP unit is mounted at ground level and the assessment position is at least 2.0 metres from the property boundary.

The barrier attenuation is calculated in the ISO model as a function of the difference in path lengths for a notional direct ray, and a ray that travels over the barrier. The purpose of the area source distributed over the top surface of the ASHP is to allow a more graduated response to changes in position for barrier attenuation.

For MCS-compliant barrier heights and samples A, B and C, the average difference between MCS and ISO models is 5 to 6 dB, but for sample D it is 1 dB. This is because Sample D requires a 10 dB barrier, and that step change puts the MCS calculation much closer to the ISO calculation. Samples A, C, and D calculated in the ISO model comfortably meet the 37 dB threshold with a lower barrier that may be preferable to the occupants, compared with the MCS barrier heights required. Sample B only requires a lower barrier in any case to qualify for the MCS 5 dB barrier attenuation, due to its physical dimensions and clearance required.

5.1.4 Differences at assessment position 2

At assessment position 2, the difference between the various ISO model configurations is small, but the difference between the ISO models and the MCS model is larger. In the scenarios presented, this position is not a constraint to the installation, so it may appear that there is nothing to gain by using an alternative sound propagation model. However, this assessment position could easily become a limiting factor if there is a window to a habitable room on the edge of the property at ground floor level. An ASHP located immediately behind a tall wall could easily fail with the MCS calculation. The ISO calculated level is consistently 11 to 12 dB lower than the MCS calculation, and therefore the ISO model could comfortably demonstrate compliance with the MCS threshold limit.

5.1.5 Differences at assessment position 3

At assessment position 3, where there is no barrier attenuation, the difference between a point source on top or at the centre reduces to insignificance. However, a significant difference between the MCS and ISO models remains, between 6 and 7 dB. This is ascribed to the different effects of the Q-factor in the MCS model and reflections in the ISO model as described above.

5.2 MCS 020 as a design driver

If the MCS method is adopted as the acoustic design driver, it leads to some potentially unexpected implications. For example, for the scenario examined here with the ASHP within 1 metre of three reflecting surfaces, it is necessary to use Q=8 in the MCS calculation. Each reflective surface adds 3 dB to the calculated result - this can be observed in Figure 6, the values in each column increase by 3 dB in subsequent rows. Conceptually, the sound power is being constrained to half the solid angle compared with the row above - radiation is into a hemisphere for Q=2, into a quarter of a sphere for Q = 4 and an eighth of a sphere for Q = 8. However, according to the MCS rules, these reflecting surfaces only qualify when they are not more than 1 metre from the ASHP. Thus by moving the ASHP away from the house facade, and away from the boundary fence until it is 1 m from each, the MCS model calculates an impact that is 6 dB lower at all assessment positions.

It is not intuitive - and unlikely in practice - that moving the ASHP less than 1 m towards assessment position 3 reduces the sound level there; equally, why should moving the ASHP away from the house facade reduce the calculated impact at any assessment position? These are the types of anomalies that result from a simple sound propagation model. However, by the time the calculated impact changes by 6 dB, these step changes are of large significance.

5.3 Differences in ISO source modelling approaches

Three different approaches are used to construct the sound source in the ISO model to examine the implications of the different approaches. The first approach, using a point source in the middle of the top surface, is intended to be a worst case, as the sound source is located closest to the assessment positions, and with the minimum barrier attenuation calculated in this model. This type of technique is generally appropriate as a first model; if the scenario complies with the sound source positioned like this, the designer can be confident that additional modelling effort is not required; a sufficient design has been demonstrated. However, if this approach is not sufficient (i.e. compliance with the impact criterion is not demonstrated), then additional modelling effort is required.

The second simple approach is to continue to use a simple point sound source, but to locate this at the geometric centre of the ASHP unit. This is arguably more appropriate for the distance attenuation, and may give a more reasonable “average” for the barrier attenuation that is calculated in the ISO model. The third approach is to use an area source, distributed across the top of the ASHP dimensions. Although in reality the main sound sources typically radiate more sound out of the front of the unit, distributing the sound source over the top surface allows for a more graduated response to barrier attenuation for different source locations, compared with a point sound source.

A fourth method using area sources over each face of the ASHP is a method favoured by some practitioners. This requires more decisions to be made - should the different faces have equal sound power per aspect, or equal sound power per unit area? Calibrating the sound sources to match the reported sound power is not simple, and mistakes can easily be made using more sophisticated source modelling.

5.4 Mix and matching models and threshold criteria

As far as the authors are aware, there are no known cases where an installation complies with MCS and a complaint has been upheld, despite hundreds of thousands of installations. By this measure it would seem that MCS is an appropriately conservative standard for permitted development rights. Previous considerations of the efficacy of MCS have focussed on the threshold limits; however, the ISO 9613 modelling presented here indicates calculated impacts that are well below the MCS calculated values, suggesting that in many real situations MCS is limiting sound impacts to much lower levels than the stated 37 dB. Could it be appropriate to mix the ISO 9613 modelling with the MCS 020 threshold criterion, by allowing installers to carry out modelling for challenging sites?

5.5 Other considerations

In practice, ASHPs also have non-uniform directivity; emerging measurements suggest that a greater proportion of sound energy is emitted in the direction of the air flow away from the machine, i.e. the direction in which the fan points. Usually this is not towards an assessment position, and therefore this means that less sound is generally emitted in the direction of an assessment position in practice. This makes an omni-directional assumption one that is usually prudent, reducing the impact to further below the calculated value.

5.6 BS 4142 approach

The conventional way of dealing with new sound sources affecting residential accommodation is to use BS 4142 to rate the significance of the impact, as noted previously. However, there are significant risks with using this approach for ASHPs for new residential development.

Firstly, the question of predicting the future background sound levels at assessment locations has significant uncertainty. There is relatively little known about predicting background sound levels compared with predicting ambient sound levels - background sound cannot be modelled from a sound source in the same way. How will future dwellings change background sound levels? How will sounds from future residents and their ASHPs affect background sound levels? It is reasonable to question whether a planning condition referring to background sound actually meets the “six tests” [12] as it fails to be “precise”, since the background sound environment will change over time.

In places with low background sound environments (e.g. below 30 dBA), planning authorities may be concerned that the sound impact from new installations needs to be even lower, e.g. targeting limits in the 20’s dBA when rating penalties are included. There is a significant risk that setting threshold limits that are likely to be below 30 dBA for the sound impact may well preclude the installation of ASHPs that would be permitted under PDR in any case. A quietly heating planet is not good for public health: a reasonable balance needs to be achieved to avoid their use resulting in adverse impacts on quality of life to meet current planning policy. Public perception of the sound impacts may be equally important.

6 RISK OF CUMULATIVE IMPACT

The risk of cumulative sound impact from the installation of multiple ASHPs in close proximity has been investigated previously [13] The study focused on the potential for adverse effects in the highest density residential areas. Scenarios examined terraced and semi-detached housing archetypes, which represent the majority of the UK's existing housing stock. The modelling assumed a series of worst-case scenarios, with all ASHPs operating at the maximum permissible sound level under the MCS 020 standard.

The findings suggest that even under these extreme conditions, the cumulative sound impact is unlikely to be significantly greater than the sound from a single, nearest-neighbour ASHP installation. The increase in sound levels due to multiple ASHPs ranged from 2-8 dB, depending on the specific scenario and receptor location. However, the biggest increases were in places where the absolute levels were low from a single unit. The study also highlighted the importance of garden fences as sound barriers, demonstrating a 1-3 dB reduction in cumulative sound levels when ASHPs were positioned next to existing garden fences, compared with being positioned more centrally on a rear facade. The specific details, such as ASHP dimensions and barrier heights that would be required, were not considered in that report.

The absolute sound levels calculated in the study remained below the threshold identified in the WHO Night Noise Guidelines, above which adverse health effects increase. In a worst-case scenario, the cumulative impact might raise background sound levels, but these levels would not exceed typical urban background sound levels. The study concluded that compliance with the existing MCS 020 sound limits for individual ASHPs should effectively prevent any significant increase in community sound levels, unless they have very low background levels.

7 CONCLUSIONS

Our analysis reveals that the MCS 020 sound propagation model consistently yields more conservative predictions than the ISO 9613-2 model, often resulting in calculated sound impacts 5 - 7 dB lower when modelled with ISO 9613-2. This finding suggests that MCS 020, while apparently effective in preventing sound complaints, may be overly restrictive in many scenarios where the sound does not have a prominent character.

On the basis of this modelling, we propose several key updates to the MCS 020 standard:

1. Implement distance calculations to the nearest 0.1 m from the ASHP's geometric centre to assessment positions.
2. Discount sound barriers as reflecting planes in determining Q-factor values.
3. Introduction of an option within MCS 020 for more detailed acoustic modelling using ISO 9613-2 by a suitably qualified person following user guidelines.

These proposals, particularly the third one, could significantly reduce unnecessary bureaucracy and costs for installations that fail the current MCS 020 assessment but would likely comply under more sophisticated modelling. A further proposal is to consider allowing sound-absorbent surfaces on reflecting planes to mitigate their impact, and neglect their presence when determining the Q-factor.

However, our findings also underscore the urgent need for further research to strike the right balance in ASHP sound standards. We propose several critical areas for future work:

1. Conduct advanced acoustic modelling, such as boundary element methods, to validate and refine existing models.
2. Gather systematic evidence from real-world installations, including detailed case studies of sound complaints, to discover if complaints have occurred when an installation complies with MCS 020.
3. Investigate the effectiveness of sound absorption on reflecting planes in practical scenarios, to enable consideration in a future revision to MCS.
4. Develop clear guidelines for implementing ISO 9613-2 modelling within the MCS framework.

By addressing these research priorities, we can develop more nuanced and effective sound control measures that balance the crucial need for ASHP adoption with community wellbeing. This approach will support the sustainable integration of this vital renewable energy technology into our built environment while maintaining acoustic protection and comfort for residents.

8 FURTHER WORK

The modelling presented in this paper suggests that further work is urgently needed to find the right balance for a sound standard for domestic ASHPs that provides sufficient protection to residents without being excessively prudent, such that it unnecessarily prevents installations. Several strands are proposed to ensure that this future work provides the robust evidence that all stakeholders require.

8.1 Updating the MCS 020 standard

The modelling presented here suggests that MCS 020 could be updated in several important ways. Using the distance measured to the nearest 0.1 m from the geometric centre of the ASHP to the assessment positions to calculate distance attenuation is a simple change. Discounting a sound barrier as also qualifying as a reflecting plane is also a simple update that is unlikely to be controversial, as evidenced by the modelling in this paper.

8.2 Use of sound absorption on reflecting planes

Another method to mitigate the more significant differences between MCS and ISO modelling would be to enable a sound absorbent surface placed on a reflecting plane behind an ASHP to qualify for omitting that surface as a reflecting plane. The differences between modelling to ISO 9613 and MCS suggest that the Q factor in the MCS leads to predictions of higher sound levels than the ISO model for equivalent geometry. Further investigations with other types of modelling, as well as practical investigations of real installations, would better inform this proposal.

8.3 Potential option for acoustic modelling to ISO 9613

The introduction of an option within MCS 020 to carry out more detailed acoustic modelling, rather than reverting to a full planning application, could save a great deal of unnecessary bureaucracy, time, and cost. Where the MCS model indicates the limit will be exceeded, more detailed modelling using the method from ISO 9613, along with appropriate guidelines, could permit installations to proceed under PDR. This approach could also be adopted by local planning authorities for new residential developments. This is the most significant new proposal in this paper that could be adopted now.

8.4 Further acoustic modelling

The modelling in this paper illustrates how for one simple context of terraced or semi-detached houses, the range of issues to consider in the acoustic modelling are broad and varied. As noted, ISO 9613 has not been developed to determine sound transmission over the short distances and around multiple building surfaces that are typical of ASHP installations. The modelling in ISO 9613 should be compared with more sophisticated acoustic modelling, such as boundary element methods (BEM) using software such as COMSOL. The accuracy of these models should be validated through comparison with measurements from real-world installations

8.5 Evidence from real installations

A systematic investigation of sound complaints is necessary to gather concrete evidence on the effectiveness of MCS 020 in real-world scenarios. This investigation should include detailed case studies of installations with reported sound issues, examining various factors that contribute to sound disturbances. By analysing the correlation between compliance and complaints, the study would aim to identify any potential shortcomings in the MCS standard and provide evidence-based recommendations for its improvement.

These proposed further works will contribute to a more comprehensive understanding of ASHP sound impacts and enable the development of more effective sound control measures that are not excessively onerous, ensuring a harmonious coexistence between this crucial renewable energy technology and our communities.

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10 APPENDIX A - FULL SET OF MODEL RESULTS

Sample # - position	ASHP L_{wA} / dB	MCS Barrier reduction to FF / dB	MCS barrier height / m	NSR Position	Barrier height to meet MCS barrier qualification. Calculated level / dBA				Calculated level for 1.8 m barrier Barrier height 1.8m			
					MCS	PT	PM	AT	MCS	PT	PM	AT
Sample A - back to house	53	5	2.29	FF	34	29.7	27.1	28.6	39	28.5	29.1	29.0
				GF	32	20.4	18.8	19.8	32	23.0	20.3	21.5
				OFF	36	29.5	29.2	29.4	36	29.5	29.2	29.4
Sample A - back to fence	53	5	1.96	FF	34	29.6	27.6	29.5	39	30.7	28.5	28.8
				GF	32	20.8	19.8	20.8	32	21.5	20.3	21.5
				OFF	36	29.3	29.1	29.3	36	29.3	29.1	29.3
Sample B - back to fence	55	5	1.54*	FF	36	30.1	28.6	30.3				
				GF	34	23.0	22.1	23.0				
				OFF	38	31.3	31.1	31.3				
Sample C - back to fence	54	5	2.09	FF	35	29.6	27.6	29.6	40	32.1	29.3	29.5
				GF	33	21.5	20.4	21.6	33	22.8	21.4	22.7
				OFF	37	30.4	30.2	30.4	37	30.4	30.2	30.4
Sample D - back to fence	58	10	2.21	FF	34	32.6	32.1	32.8	44	32.6	31.5	33.2
				GF	37	25.0	24.1	25.0	37	26.7	25.4	26.7
				OFF	41	34.3	34.1	34.3	41	34.3	34.1	34.3

* Modelled with a 1.8 m barrier height