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THE ROLE OF MEASUREMENT LOCATIONS IN LOW-FREQUENCY NOISE ASSESSMENT

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ABSTRACT

With the increasing use of heat pumps as a sustainable solution for heating and cooling, their acoustic impact on the environment has become of crucial importance. Heat pumps are acoustically complex sources that can be controlled by smart algorithms and have specific low-frequency characteristics that differ from well-studied sources. An accurate noise assessment of heat pumps requires careful consideration of the measurement locations, as these have a direct influence on the characterization of noise emissions and their potential impact on the environment. In this study, the influence of the measurement locations on the low-frequency noise levels is investigated, including the positions in front of the façade, on the façade and in the free field. A loudspeaker and a custom-built low-frequency sound source are used to generate the low-frequency sound. The results show significant differences in the measured sound pressure levels depending on the position of the receiving point in relation to the low-frequency sound source. By emphasizing the importance of selecting appropriate measurement locations, this work is intended to assist acoustics professionals and policy makers in establishing robust standards for the assessment of heat pump noise.

Keywords: *low-frequency sound, frequency weighting,facade, microphone position, environmental noise*

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1. INTRODUCTION

Sound levels are often assessed in dwellings, at the most exposed façade where the sound field is determined by reflections and diffraction. To ensure reproducibility and comparability of results, guidelines such as ISO 1996-2 [1] or ISO 16283-3 [2] suggests a +3 dB correction when the microphone is located between 0.5 and 2 m from a reflecting surface, and up to + 6 dB (with default value of +5,7 dB) correction when the microphone is placed directly on the surface. However, factors such as the source-receiver geometry, the nature of the noise source (e.g., point source vs. line source), the composition of the façade materials, and the presence of other reflective or scattering surfaces can influence the actual reflection contribution. Research has indicated that in many practical measurement situations, the +3 dB and +6 dB approximations might not be appropriate, with some studies suggesting smaller correction values. Furthermore, the source-façade distance (D) and the microphone-façade distance (d) have been identified as important parameters influencing the reflection effects [3–11]. Given the potential for discrepancies between standardized corrections and real-world measurements, ongoing research is essential to refine the guidelines for noise assessment near building façades. This includes investigating the accuracy of existing correction factors for new sound sources such as heat pumps, which are becoming an integral part of the built environment. Heat pumps are acoustically complex sources that can be controlled by intelligent algorithms, differ from well-studied sources by their specific frequency and operational characteristics and are often placed in locations where the resulting sound field is affected by multiple reflections or where the receiver is in the near sound field. An accurate noise assessment of heat pumps requires careful consideration of the measurement locations, as these have a direct influence on the characterization of noise emissions and their potential impact on the environment. The aim of this study is to carry out an initial experimental investigation of the influence of the measurement locations on the measured low-frequency sound levels. A loudspeaker producing 125 Hz octave band noise is used to perform measurements in an otherwise anechoic room and a custom-made sound source emitting a 50 Hz tone is used to perform measurements in the real environment. The acoustic measurements include the positions in front of the façade, on the façade and in the free field. The analysis of the measured sound levels should provide initial insights into the correction factors for façade measurements of low-frequency sound and their dependence on relevant parameters.

2. METHODOLOGY

In the experimental study, two low-frequency sound sources were used and the signals were recorded with class 1 sound level analyzers, which were checked with a sound calibrator before and after the measurements. The measurements were carried out in an anechoic chamber and in a real environment. To gain an initial insight, various incidence configurations and different microphone positions were investigated.

2.1 Measurements performed in an anechoic environment

The signals were recorded using Norsonic 140 Class 1 sound analyzers with a 1/2-inch preamplifiers type 1209 and a Nor1225 free-field microphones. The preamplifier and microphone were connected to the analyzer via a cable. A windscreen was not used. The source was a B&K HP 1001 loudspeaker driven by a B&K type 4205 generator. The loudspeaker was used to generate a wide band signal (white noise) in the frequency range from 100 Hz to 100 kHz and a 125 Hz octave band noise. The sound power level was set to 95 dB. The microphone locations included positions on the facade and in the free field. For the free-field position, the microphone was placed in front of the wall of the room made of pyramid-shaped glass wool elements. For the position on the facade, the microphone was mounted against a painted 20 mm chipboard panel. In both cases, the microphone was directed towards the sound source at an 90^0 degree angle of incidence. Two series of measurements were performed with different microphone and source positions to simulate normal (0^0) and parallel (90^0) incidence:

a) For the first configuration, the loudspeaker was placed at a distance of 2 m in front of the microphone.

b) For the 90^0 incidence, the loudspeaker and the microphone were placed in the same horizontal plane. The distance between the loudspeaker and the receiver was 1.55 m. The measurement setup with the loudspeaker and the free field microphone is shown in Fig. 1

In both series, the signals (125 Hz octave band and 100 Hz – 10 kHz white noise) were first recorded with the microphone at the facade position. Then the plate was removed, and free-field measurements were made. Each recording was at least 3 minutes long.

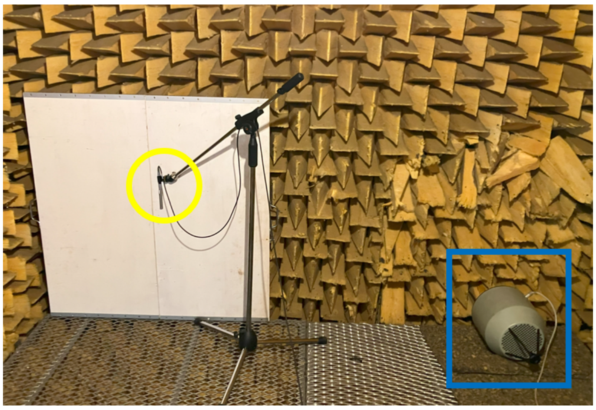

Figure 1. The 90^0 incidence measurement setup in the anechoic room with the loudspeaker (blue square) and the facade microphone (yellow circle).

2.2 Measurements performed in the real environment

The measurements were carried out on a two-storey house. The south façade (S façade) of the house is made of brick and has two windows and a door. The length of the S façade is 13.5 m, and the maximum height is around 8 m. The ground in front of the S façade is an acoustically hard. The western part of the brick façade (W façade) has 4 windows, is 15 m long and 7 m high. The ground in front of the façade consists of grass (soft ground).

The signals were recorded with two Norsonic 140 Class 1 sound analyzers and the windscreen was used. The sound source was a loudspeaker connected to an electrical transformer and housed in a square wooden box measuring 500 mm x 500 mm x 500 mm. The source emitted a very intrusive 50 Hz tonal sound. The emission characteristics of the source was determined by measurements at a distance of 2 m and at a height of 2 m from the surfaces of the box in four directions. The equivalent continuous A-weighted sound pressure level ($L_{\mathrm{Aeq,T=2min}}$) was in the range of 55.9 dB(A) to 56.9 dB(A). The equivalent continuous C-weighted sound pressure level ($L_{\mathrm{Ceq,T=2min}}$) was in the range of 83.1 dB(C) to 83.5 dB(C). The equivalent continuous sound pressure level in the 50 Hz one-third octave band ($L_{\mathrm{eq,50Hz,T=2min}}$) was in the range of 84.7 dB to 83.3 dB. Based on the emission measurements, the source was considered omnidirectional. At a distance of 4 m from the source, $L_{\mathrm{Aeq,T=2}}$ min, $L_{\mathrm{Ceq,T=2min}}$ and $L_{\mathrm{eq,50Hz,T=2min}}$ min were reduced by 5.5 dB(A), 6 dB(C) and 6 dB respectively, so that the source was considered to be a point source.

The microphone locations included positions on the façade (façade position), near a façade (near position) and in the free field. Three series of measurements were carried out with different microphone and source positions:

a) In the first series, the interference pattern expected due to façade reflections was investigated. The sound source was placed on the ground at a distance of 12.4 m from the S façade. One microphone was placed on the façade at a height of 3.6 m relative to the source height. The distance of the second microphone to the source was varied at 2 m, 4 m, 9.2 m and 10.8 m.

b) In the second series, the influence of the distance between the facade and the source was tested. The source were initially positioned on the ground at a distance D = 15.1 m from the S façade. One microphone was placed on the façade at a height of 3.6 m relative to the source height. The position of the second microphone was varied. It was placed in the free field (10 m from the source and 5 m from the SW edge of the house) and in the near field, where strong interference effects are expected, at 1.7 m and 3.2 m from the façade. The measurements were repeated, only this time the source was placed at a distance D = 10.0 m from the S façade and the second (free field) microphone at a distance of 10 m from the source.

c) In the third series, the influence of the angle of incidence was investigated. The source was placed on the ground at a distance of 0.3 m from the W façade. The microphones were placed at a distance of 4.5 m on the same horizontal plane to simulate the 90^0 incidence. One microphone was placed on the façade and the other microphone in the free field (2.8 m from the SW edge of the house). The measurement setup with the loudspeaker and the free field microphone is shown in Fig. 2.

For each series and each microphone–source configuration, the source signal was averaged for at least 10 minutes. All unwanted sound events and removable residual noise signals were removed. The recordings included distant low-amplitude background noise sources, such as birdsong and distant road noise, which could not be excluded.

Figure 2. The 90^0 incidence measurement setup with the loudspeaker (blue square) and the free field microphone (yellow circle).

3. RESULTS AND DISCUSSION

3.1 Measurements performed in an anechoic environment

The measurement results for both series include A- and C-weighted levels (Tables 1 and 2) and 1/1-octave frequency analysis in the 16 Hz – 20000 Hz range (Figure 3). The integration time interval was 3 minutes long.

At normal (0^0) incidence, the expected difference between the levels at the facade and free field positions is about 6 dB, assuming perfect reflection, and should be less otherwise [4, 12]. At normal incidence, the L_{Aeq} values at the façade for both sources were about 6 dB(A) higher than in the free field, which is to be expected if perfect reflection is assumed. The difference in L_{Ceq} values was 2.2 dB(C) and 6 dB(A) for the 125 Hz octave band and the broadband signal respectively. The same trend was observed for the $L_{\mathrm{eq,125Hz}}$ level, emphasising that L_{Aeq} cannot always be used to evaluate the difference between façade and free field when the level difference comes from

Table 1. $L_{\text{Aeq,T=3min}}$ and $L_{\text{Ceq,T=3min}}$ levels in the anechoic room for normal (0^0) and parallel incidence (90^0) for the 125 Hz octave band source.

0^0	Facade	Free-field
L_{Aeq}	59.4	53.6
L_{Ceq}	72.3	70.1
90^0	Facade	Free-field
L_{Aeq}	56.1	56.8
L_{Ceq}	71.5	73.7

Table 2. $L_{\text{Aeq,T=3min}}$ and $L_{\text{Ceq,T=3min}}$ levels in the anechoic room for normal and parallel incidence for the wide band 100 Hz - 10 kHz source.

0^0	Facade	Free-field
L_{Aeq}	86.2	80.8
L_{Ceq}	86.0	80.5
90^0	Facade	Free-field
L_{Aeq}	78.9	73.4
L_{Ceq}	79.5	75.3

low frequencies.

At 90^0 incidence the expected difference between the facade and free field levels should be close to 0 dB. However, the measurement results indicate that the levels in the free field can be even greater than the levels at the façade, as observed in the case of the 125 Hz octave band source. The difference between the A-weighted façade and free-field levels for the low-frequency source was positive (+0.7 dB), while the difference between the $L_{\text{eq,125Hz}}$ levels was negative (-2.5 dB). L_{Ceq} followed the $L_{\text{eq,125Hz}}$ trend. The level differences for the broadband noise source, to which the high frequencies make a significant contribution, are probably largely determined by their directivity pattern.

3.2 Measurements performed in the real environment

Fig.4 shows a typical one-third octave band spectrum in the range 20 Hz – 20 kHz, measured at a distance of 2 m from the source. The spectrum is characterized by a

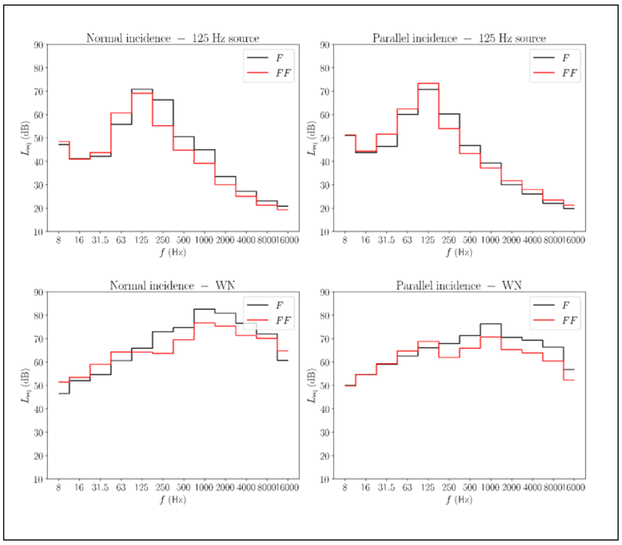

Figure 3. Octave band sound pressure level spectra, measured in an anechoic room for the low-frequency 125 Hz octave band sound source for (a) normal and (b) 90^0 incidence and for the wide band sound source for (c) normal and (d) 90^0 incidence.

pronounced tone at 50 Hz. The results therefore include A-weighted (L_{Aeq}), C-weighted levels (L_{Ceq}) and one-third octave band levels in the 50 Hz band $L_{\text{eq,50Hz}}$.

3.2.1 Interference pattern

The levels $L_{\text{Aeq,T=10min}}$, $L_{\text{Ceq,T=10min}}$ and $L_{\text{eq,50Hz,T=10min}}$ as a function of distance from the source are shown in Fig. 5. The distance between the source and the facade is 12.4 m. The measured values are shown as dots. The dashed prediction curves represent the sound attenuation due to the geometric spreading for a point source.

L_{Ceq} and $L_{\text{eq,50Hz}}$ points far from the source and are located near and on the façade deviate significantly from the prediction curve. The levels at a distance of 3.2 m from the façade are similar to the façade levels and the levels at a distance of 1.7 m from the façade are significantly lower, which is in good agreement with the theoretical analysis of the sound fields at the boundaries. The L_{Aeq} levels show less variation near and at the façade and the interference pattern is not clear.

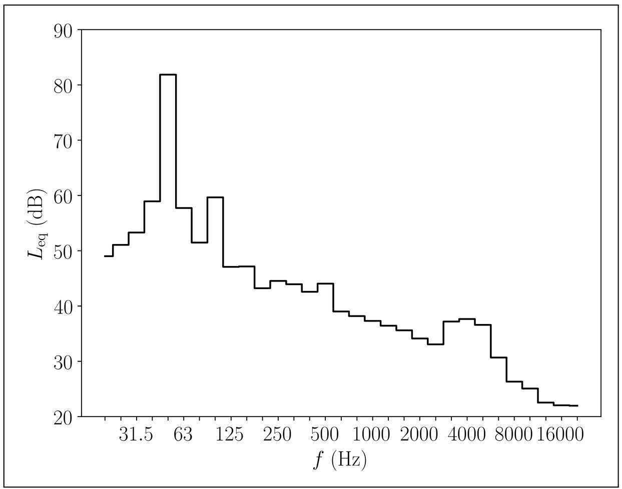

Figure 4. Third-octave band sound pressure level spectrum in the range 20 Hz – 20 kHz, measured at a distance of 2 m from the source.

3.2.2 *Source-facade distance*

The levels $L_{\mathrm{Aeq,T=10min}}$, $L_{\mathrm{Ceq,T=10min}}$ and $L_{\mathrm{eq,50Hz,T=10min}}$ and the distance between source and microphone (r) in the near field (1.7 and 3.2 m from the façade), at the façade and in the free field when the source was placed at a distance of D = 15.1 m and D= 10 from the façade are shown in Tables 3 and 4 respectively.

Table 3. $L_{\mathrm{Aeq,T=10min}}$, $L_{\mathrm{Ceq,T=10min}}$ and $L_{\mathrm{eq,50Hz,T=10min}}$ at source – facade distance D = 15.1 m and different microphone positions. NF (3.2 m) = near field (3.2 m from facade), NF (1.7 m) = near field (1.7 m from facade), F = facade, FF= free-field

r (m)	$L_{\mathrm{eq,50Hz}}$	L_{Aeq}	L_{Ceq}	Position
11.9	68.0	42.9	67.1	NF (3.2 m)
13.4	63.8	43.4	63.5	NF (1.7 m)
15.1	68.5	42.6	67.6	F
15.1	64.6	42.5	63.2	FF

The $L_{\mathrm{eq,50Hz}}$ was highest at the façade and at the near-field position at 3.2 m from the façade. The $L_{\mathrm{eq,50Hz}}$ was lower at the free-field and near-field positions (1.7 m from the façade). As expected, L_{Ceq} reflects the trend at 50

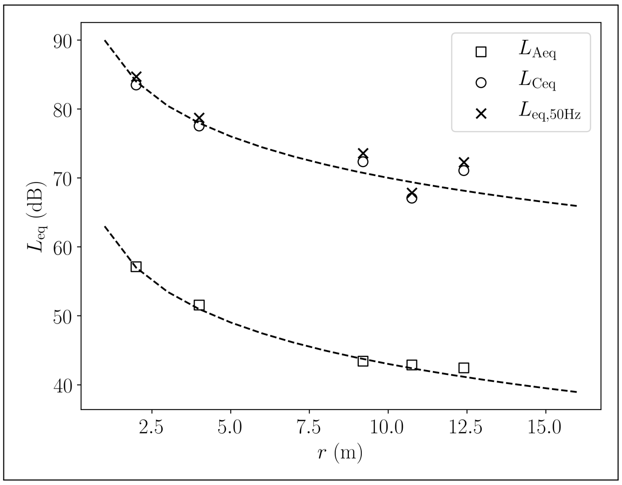

Figure 5. The levels $L_{\mathrm{Aeq,T=10min}}$, $L_{\mathrm{Ceq,T=10min}}$ and $L_{\mathrm{eq,50Hz,T=10min}}$ as a function of distance from the source

Table 4. $L_{\mathrm{Aeq,T=10min}}$, $L_{\mathrm{Ceq,T=10min}}$ and $L_{\mathrm{eq,50Hz,T=10min}}$ at source – facade distance D = 10.0 m and different microphone positions. NF (3.2 m) = near field (3.2 m from facade), NF (1.7 m) = near field (1.7 m from facade), F = facade, FF= free-field

r (m)	$L_{\mathrm{eq,50Hz}}$	L_{Aeq}	L_{Ceq}	Position
6.8	73.3	46.0	72.1	NF (3.2 m)
8.3	67.4	44.4	66.8	NF (1.7 m)
10	73.3	45.2	72.2	F
10	69.4	44.4	68.3	FF

Hz, while L_{Aeq} values are consistent across all positions. The L_{Aeq} values do not follow the interference pattern. This behaviour is very consistent at both distances between source and facade. The L_{Ceq} and $L_{\mathrm{eq,50Hz}}$ level differences between the façade and free-field positions are uniform at around 4 dB.

3.2.3 *90^0 incidence*

The levels $L_{\mathrm{Aeq,T=10min}}$, $L_{\mathrm{Ceq,T=10min}}$ and $L_{\mathrm{eq,50Hz,T=10min}}$ at the façade and in the free field are shown in Table 5 respectively.

The free-field $L_{\mathrm{eq,50Hz}}$ and L_{Ceq} values were slightly

Table 5. $L_{\mathrm{Aeq,T=10min}}$, $L_{\mathrm{Ceq,T=10min}}$ and $L_{\mathrm{eq,50Hz,T=2min}}$ at façade and free field positions for the 90^0 incidence configuration in the real environment. F = facade, FF= free-field.

Position	$L_{\mathrm{eq,50Hz}}$	L_{Aeq}	L_{Ceq}
F	79.5	52.0	78.3
FF	80.3	51.6	79.2

higher than the façade values, while L_{Aeq} showed the opposite trend. The differences were not considered significant, however the higher low frequency level in the free field was also observed in the anechoic room. A default facade correction would probably not be justified in such cases, as the façade seems to have only a very small influence on the measured values.

4. CONCLUSION

The evaluation of the difference between façade and free-field sound pressure levels is a complex task, even when a simple low-frequency sound sources is investigated. In this study, the A-, C-weighted, octave and one-third octave band sound pressure levels in front of the façade, on the façade and in the free field were experimentally investigated in order to gain initial insights into the façade correction factors for low-frequency noise. The experiments were carried out in a controlled environment (anechoic room) and in a real environment.

In the anechoic room, a 125 Hz octave band sound signal was used to determine the difference between L_{Aeq} , L_{Ceq} and $L_{\mathrm{eq,125Hz}}$ levels at the façade and the free-field microphone positions at normal and 90^0 incidences. The results showed that the characterization of the façade correction in the anechoic room using A-weighted levels was only successful at normal incidence using a wide band white noise signal with sufficient energy in the high frequency range. For the low-frequency 125 Hz octave band source, C-weighted and band levels were better suited to characterize the effect of sound reflection and angle of incidence on the resulting sound field. At 90^0 incidence, the measurement results showed that the free-field levels can be even greater than the façade levels when a 125 Hz octave band source was used.

A custom-built source emitting a 50 Hz tone was then used to conduct field experiments in a real environment. Three series of measurements were carried out to investigate the interference pattern, the effect of the distance between the source and the façade and the façade corrections for 90^0 incidences of low-frequency tonal sound at 50 Hz. The L_{Ceq} and $L_{\mathrm{eq,50Hz}}$ values were closely correlated and could be attributed to the interference patterns, the effects of the angle of incidence and the lower reflection characteristics associated with low-frequency sound. One of the test results is also that low-frequency sound levels could be underestimated if the standard façade factor (5.7 dB(A) or 6 dB(A)) is used to correct the A-weighted sound pressure levels measured at the façade at large angles of incidence.

5. ACKNOWLEDGMENTS

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