Comparisons of Various Approaches to Low Frequency In-Situ Measurements and Corresponding Models

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ABSTRACT

New recommendations for environmental noise levels have been issued in Sweden. The permissible levels at facades of new buildings have been increased, which has resulted in a risk for higher indoor low frequency noise levels, since the recommended indoor levels are A-weighted. The additional Swedish low frequency third octave band requirements might be violated. Therefore, there is a need for reviewing how well façade insulation properties are manifested in measurements, and how accurate the measurement results indicate the indoor noise situation from the residents' perspective.

In this paper, the results of façade insulation measurements are compared with corresponding models, with a special attention to associated challenges (e.g. to establish representative microphone positions in low frequency sound fields). The measurements are performed in a demonstrator house, which replicates a modern single family house. The models are evaluated both with respect to the total sound energy integrated over the entire room volumes, and as sampled sound fields, where the sample points may correspond to microphone positions. The congruence of the measured and the modelled results are analysed and discussed, as well as the relevance of different approaches.

Keywords: Sound, Insulation, Transmission I-INCE Classification of Subjects Number(s): 51.4

1. INTRODUCTION

The maximum recommended level in the Swedish regulations for environmental noise at facades has for many years been 55 dBA 24-hour equivalent level. But this upper level was recently completely removed for housings where half of the rooms of the dwelling were facing a quiet side (which was defined as 55 dBA 24-hour equivalent level).

An evaluation of existing buildings by Rusz et al. (1) indicated that even modern buildings in general may have problems with, in particular, low frequency noise if the general noise level is high and low frequency noise is a substantial part of this

One of the challenges is to make measurements in the low frequency region. In particular, it is not obvious how to characterize a room from measurements in frequency regions where transitions of modal patterns occurs; i.e. the region extending from the frequencies where the first modes start to evolve, up to the where modal overlap begins to even out amplitude variations of individual modes in the room.

In Sweden, this challenge has resulted in a new guiding scheme for national regulation measurements in rooms (2), to use as a support for reducing uncertainties in measurements according to SS-EN ISO 10052 and SS-EN ISO 16032, in particular in the low frequency region. The scheme was originally prompted by a need to assess the low frequency third-octave band requirements for indoor noise according to Swedish national regulations (3), which are extended down to the 31.5 Hz third-octave band. There have also been indications from multi-storey dwellings with light-weight construction floors that noise measurements down to 20 Hz are needed to predict the level of annoyance associated with certain floor types (4), which has supported the foundation for extending the measurement range downward in frequency.

The Swedish low-frequency measurement scheme is not designed to be used in presence of external

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sounds or together with façade insulation measurements according to e.g. the ISO 16283-3:2016 standard, since the recommended sampling scheme (of microphone positions) does not account for various transmission paths. However, there is a current discussion whether the Swedish national regulations for low frequency noise also should be applied in case of external sound sources as traffic noise et cetera, which opens up the question whether the Swedish low-frequency measurement scheme can be extended to be used for e.g. façade measurements.

In order to assess how well the sampling scheme performs in a room which deviates from an ordinary shoe box shape, a set of façade insulation measurements were performed in-situ in an asymmetric room of a demonstrator house, which replicates an ordinary family housing. The measurements are here compared with the eigenmodes of a corresponding numerical model of the room, to assess how well the microphone position scheme represents the low frequency sound field. The models are evaluated both with respect to the total sound energy integrated over the entire room volumes, and as sampled sound fields, where the sample points may correspond to microphone positions.

2. MEAUREMENTS

The measurements were performed in a pre-fabricated low energy wooden framed villa. The house is a replica of a modern single family and was built as a demonstrator for the research project NEED4B at the premises of SP Technical Research Institute of Sweden, in Borås. A room on the second floor (above the ground/first floor) with an irregular shape was chosen for the measurements (cf. Figure 1 and Figure 2).

Figure 1 – The investigated house, with a circle showing the position of the room in which the measurements were performed.

The façade insulation properties were measured according to ISO 16283-3:2016, with modifications in the low frequency region according to the Swedish sampling scheme (ISO 16283-3:2016 is intended for the frequency range of 50 Hz to 5 kHz). The measurements were performed with a high frequency resolution (1.5 Hz) and extended down to below 10 Hz, although the excitation signal started to drop rapidly below 20 Hz, making 16 Hz an approximate lower limit for reliable results. The indoor sound was measured with microphones positioned as indicated in Figure 2 and Table 1. The outdoor sound was measured with a microphone attached to the outside of the window, with adhesive tape (cf. Figure 3).

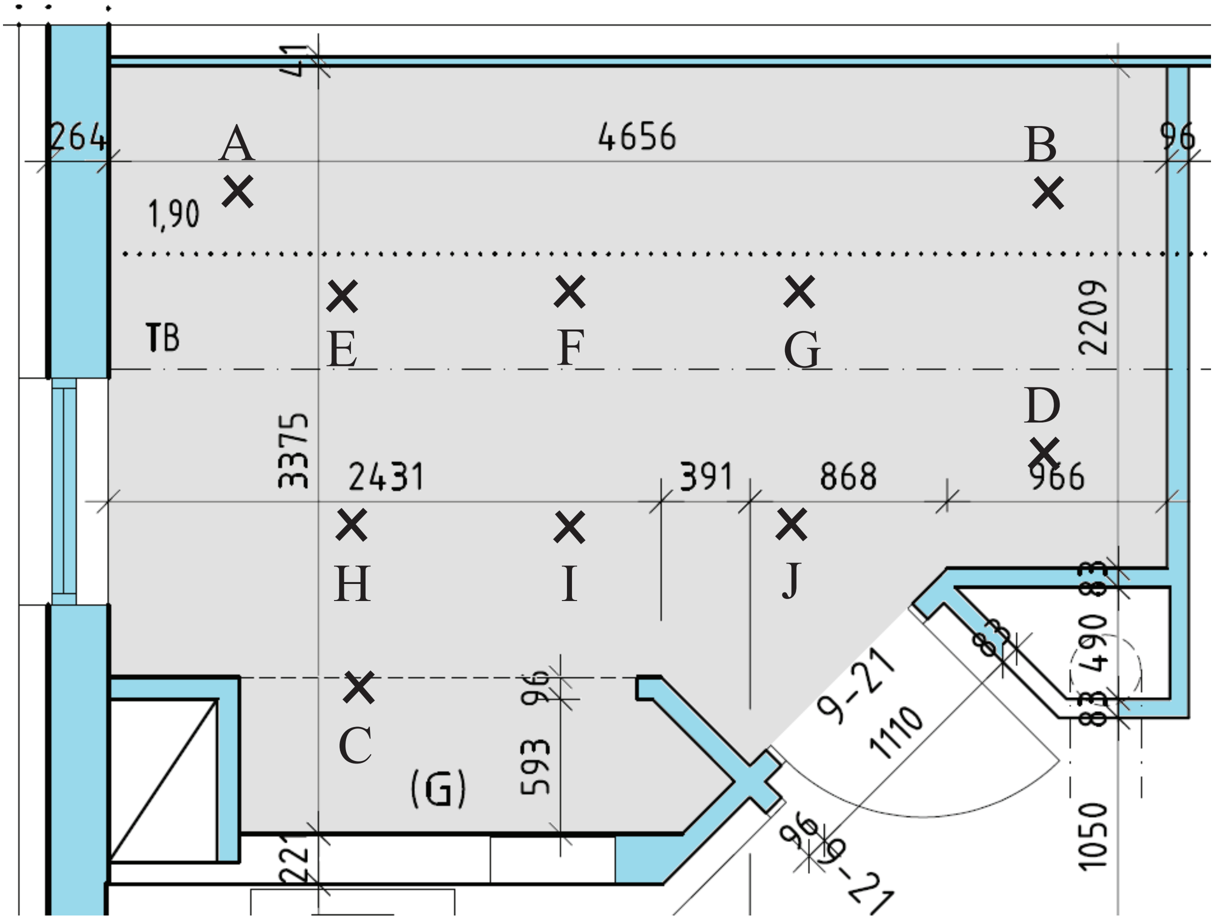


Figure 2 – 2D drawing of the investigated room. The microphone positions are designated A-J, and specified in Table 1, below.

Table 1 – Microphone positions

Position	Microphone Height		Distance from	
			Nearest corner (x,y)	Upper left corner (x,y)
A	0.5 m	-	0.5 m, 0.5 m	-
B	0.5 m	-	0.5 m, 0.5 m	-
C	0.5 m	-	0.5 m, 0.5 m	-
D	0.5 m	-	0.5 m, 0.5 m	-
E	1.20 m	-	-	1 m, 1 m
F	1.20 m	-	-	2 m, 1 m
G	1.20 m	-	-	3 m, 1 m
H	1.20 m	1.60 m	-	1 m, 2 m
I	1.20 m	1.60 m	-	2 m, 2 m
J	1.20 m	1.60 m	-	3 m, 2 m

A set of two loudspeakers and four subwoofers were used as sound generators and placed at a 45° angle from the corner nearest corner of Figure 1, which is the top left corner of Figure 2. A sine sweep and an MLS signal was evaluated and, since both methods gave similar results at the same measurement positions, the MLS signal was selected for the measurements as it gave a slightly better signal to noise ratio.

Figure 3 – The microphone was attached to the window with adhesive tape (left). The construction details and individual elements are well documented. The picture to the right shows a cross-section of the façade.

3. NUMERICAL MODEL

The room was also modelled with a simple FEM fluid model (Figure 4), in order to evaluate if the lowest calculated room eigenmodes could be traced in the measurements. The boundary conditions are set to rigid walls for all surfaces, which is a rather coarse approximation. In particular, most of the sound in the room can be supposed to be generated by movement in the walls.

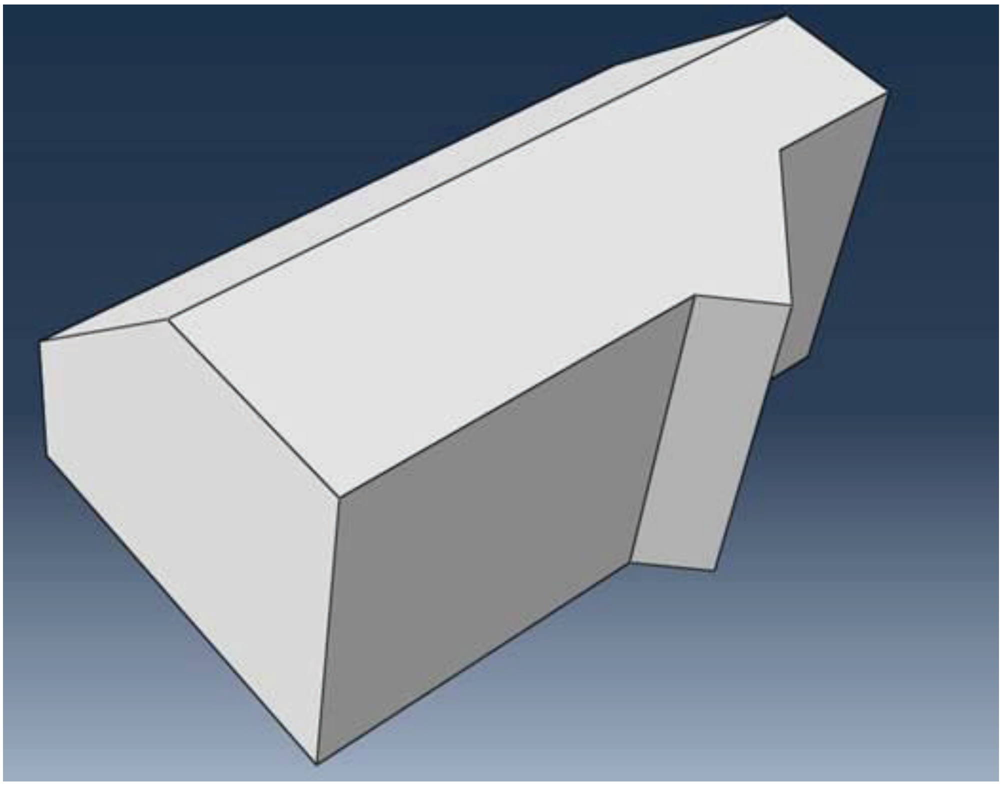
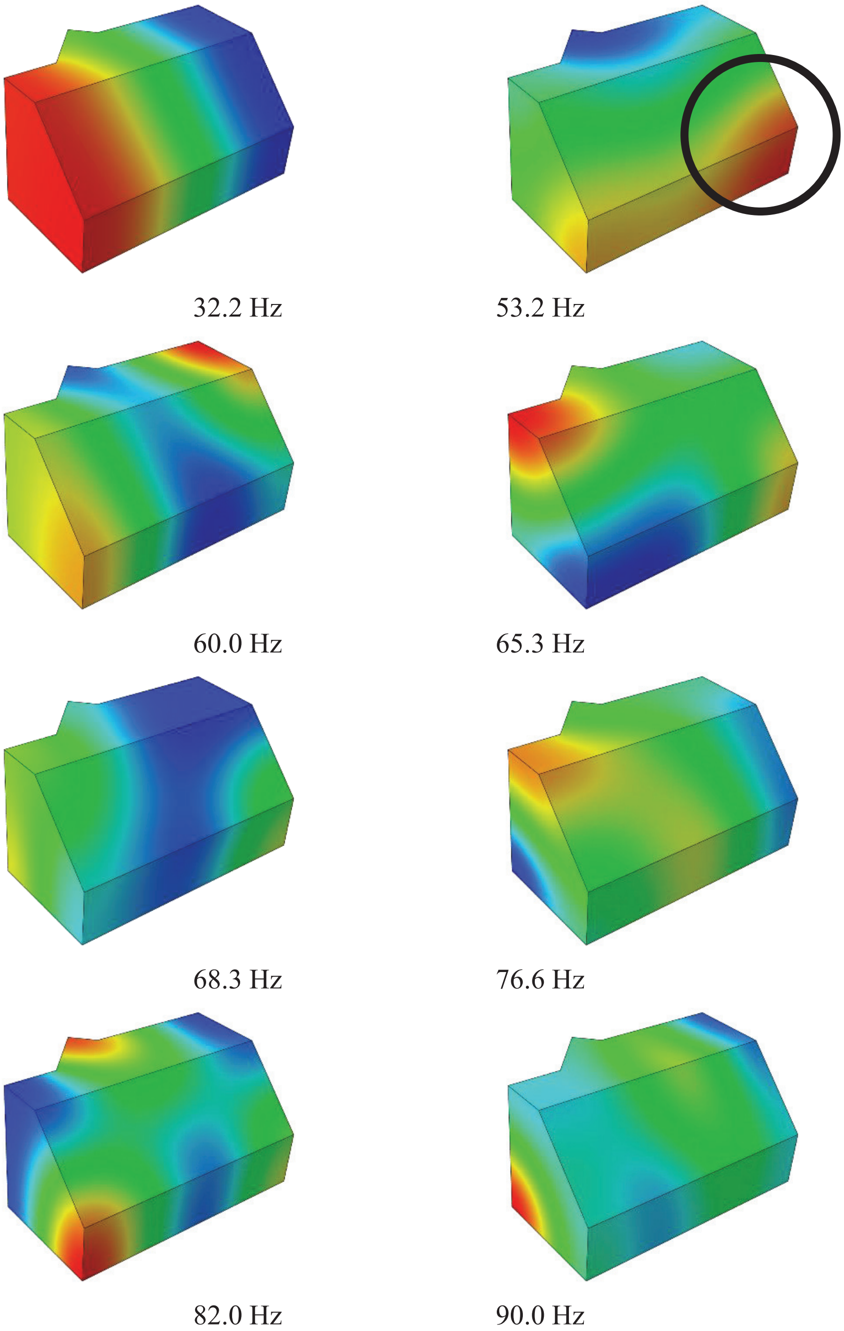


Figure 4 – 3D model for numerical simulation of the evaluated room

4. RESULTS

4.1 Numerical Calculation

The eigenmodes from the numerical calculations up to 90 Hz are shown below in Figure 5. As can be expected, the lowest mode is quite regular, while the higher modes are increasingly complex and irregular. The focus here was to evaluate if any trace of the modal shapes of the low eigenmodes could be found in the measurements. This is not evident, since the boundary conditions are rigid walls, which would imply that the measured resonances are lower in frequency. Also, the modal distribution will also be affected by the sound transmitting walls. Only the two lowest modes are well separated in frequency.



32.2 Hz 53.2 Hz

60.0 Hz 65.3 Hz

68.3 Hz 76.6 Hz

82.0 Hz 90.0 Hz

Figure 5 – The first calculated eigenmodes of the fluid model. The two first modes (at 32 Hz and 53 Hz, top left and top right, respectively) are well separated in frequency, but the next modes are closer, and a certain modal overlap will occur. The modal patterns are increasingly irregular, as can be expected.

4.2 Measurements

The façade insulation properties were measured, but in this paper the focus will be on the spatial distribution of the sound field in the room. In the low frequency region of the zero mode, there are some minor variations of the relative sound pressure level at the various microphone positions in the inner part of the room (Figure 6). The variations at the corners are typical of a bigger magnitude. From 20 Hz and upward the sound field distribution is approaching that of the first mode, which is most pronounced around 34 Hz (further commented below).

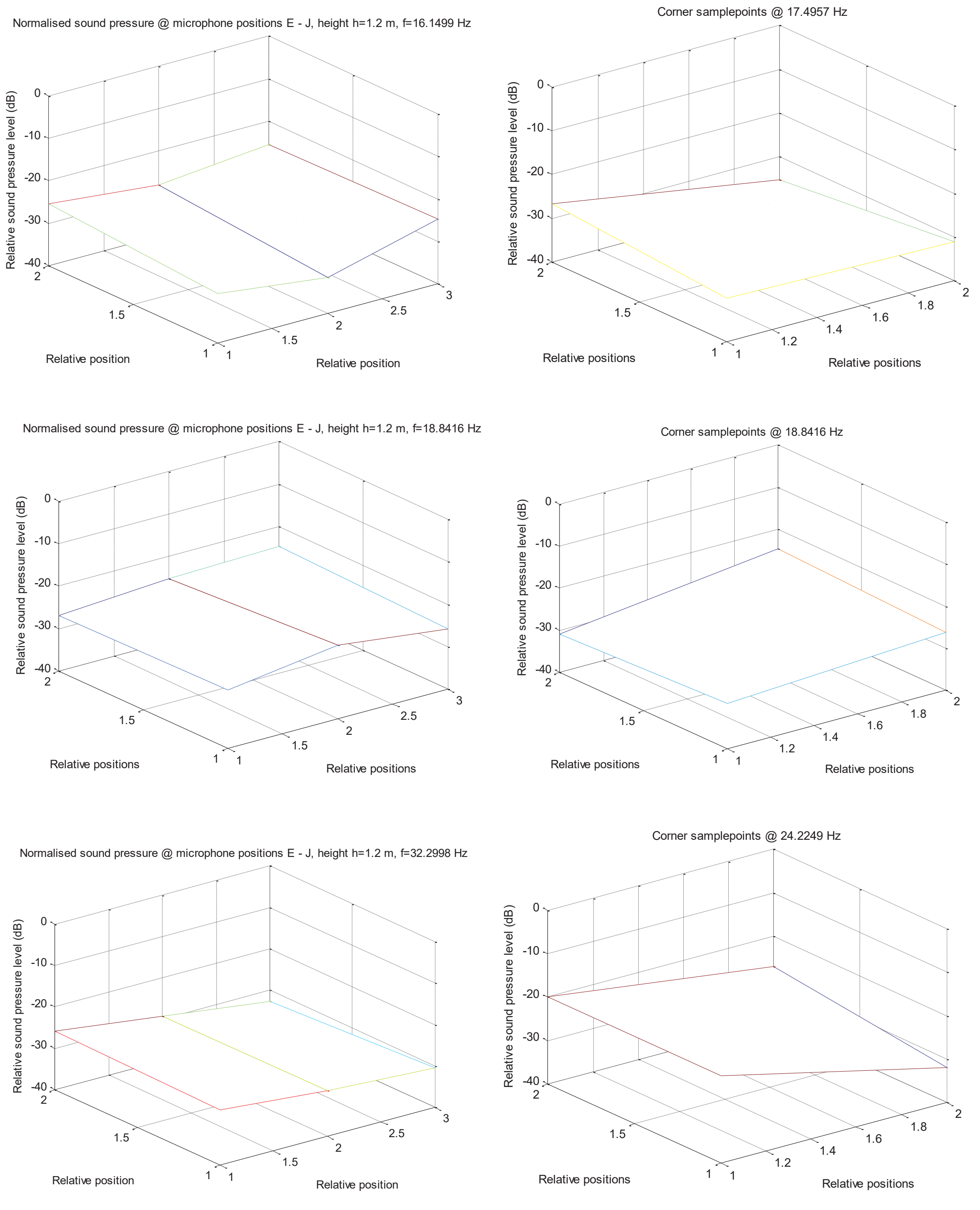


Figure 6 – Left: The sound field at the microphones E – J, placed in the interior of the room at the height h=1.2 m. Top-down: At 16 Hz, 19 Hz and 32 Hz (first mode). Right: The four corner positions, top-down: At 17 Hz, 19 Hz and 24 Hz (as can be seen the sound field distribution is approaching that of the first mode).

4.3 Comparison of Measurements and Calculations

The calculated modal shape of the first mode can quite clearly be seen in the measurements, around the predicted frequency, despite the coarse approximations made in the calculations.

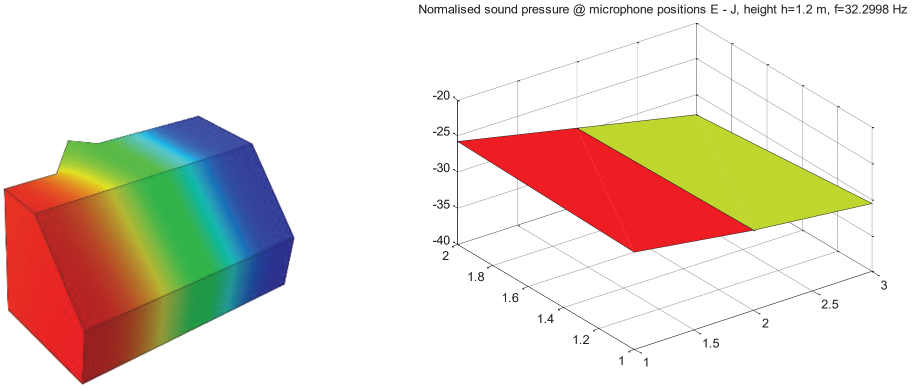


Figure 7 – The first mode frequency and modal shape are in better agreement between measurements and calculations than can be expected, considering the numerical approximations

The second mode can also be traced in the measurements, around the predicted frequency, but the modal shape similarity is not as distinct in this case. The same corner is dominating in the calculations and in the measurements, but the next strongest corner according to the calculation was the weakest in the measurements, cf.

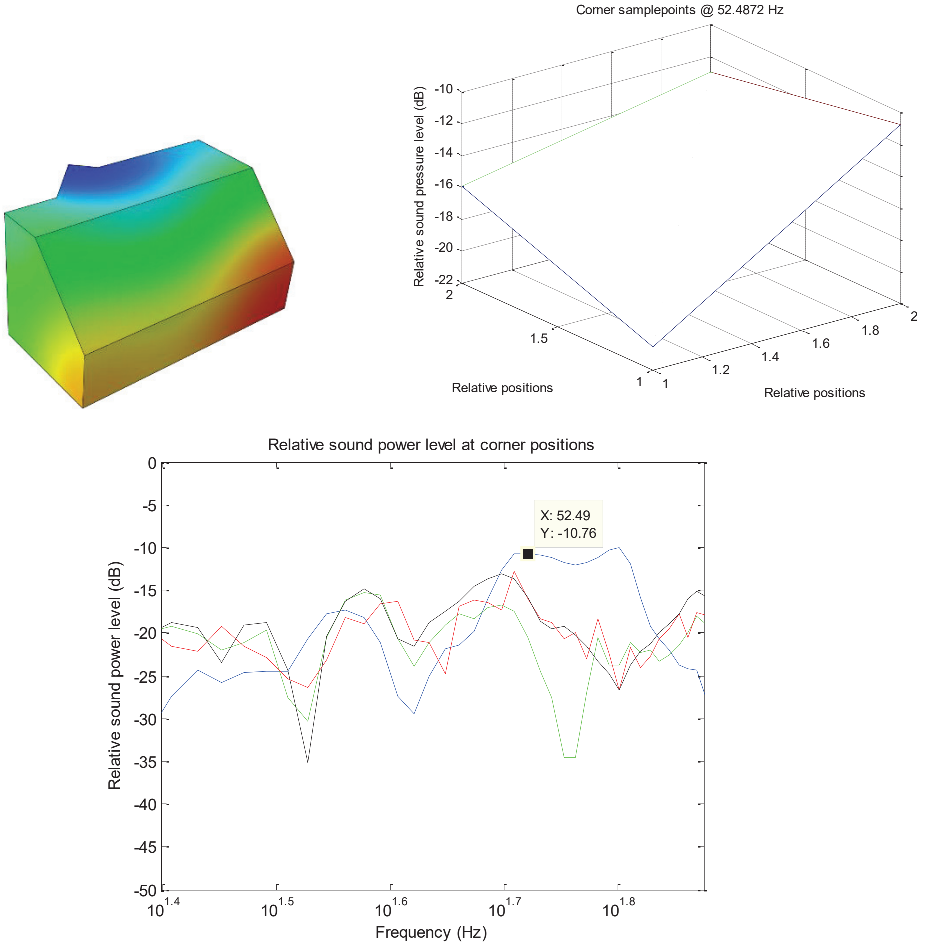


Figure 8 – The second mode frequency and modal shape that was obtained from the calculations can be identified in measurements, but there are some deviations.

5. DISCUSSION AND CONCLUSIONS

Measurements and numerical calculations were made on an irregular shaped room in a replica of a modern family house. The first two calculated eigenmodes at 32 Hz and 53 Hz, respectively, were compared with the sound field of the room, which was evaluated during façade insulation measurements. The eigenmode calculations were performed on a fluid model with all boundaries set to rigid walls, which is quite far from the real case. In particular, the sound field in the room was probably too a large extent driven by the walls. Still, the calculated first mode coincided both with respect to the shape and the frequency with what was found in the measurements. The second mode showed also similarities, both with respect to frequency and shape, with exception for one of the corners. In the zero mode frequency range, the variations were modest in the interior of the room, but the corners showed larger variations. However, the modal shape of the first mode was clearly observable from 20 Hz and upwards, making the sound field rather consistent in that frequency range.

The new Swedish national regulations for environmental noise at façades have triggered discussions of how to assess low frequency façade insulation properties, and low frequency noise from external sources. Our initial evaluations indicate that the lowest modes may be rather uncomplicated even for quite irregular room shapes. The measurement challenge in that frequency range is largely a philosophic question of what is a relevant representation of a room with an uneven sound field, but the sound field shape may be possible to model with a low effort. Obviously, when the sound field gets more irregular for higher order modes, the challenges will increase.

ACKNOWLEDGEMENTS

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REFERENCES

1. Rusz R, Cinkraut J, Sound Transmission of House Facades at Low Frequencies, KTH Master Thesis, supervisor Svante Finnveden, 2015
2. Larsson K, Simmons C. Vägledning för mätning av ljudnivå i rum med stöd av SS-EN ISO 10052/16032, in Swedish, SP Report 2015:02.
3. Blom N. Folkhälsomyndighetens allmänna råd om buller inomhus. Swedish national guidelines from Public Health Agency of Sweden, in Swedish, FolkhFoHMFS 2014:13
4. Simmons C, Ljunggren F, Hagberg K. Findings from the AkuLite project: New single numbers for impact sound 20-5000 Hz based on field measurements and occupants’ surveys
5. SS-EN ISO 16283-3:2016, Acoustics -- Field measurement of sound insulation in buildings and of building elements -- Part 3: Façade sound insulation