



BNAM 2018
Baltic-Nordic Acoustics Meeting
15-18 April 2018
Harpa, Reykjavik, Iceland

Low frequency sound insulation (8-200Hz) – mapping and improvement of existing houses

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This paper presents the results of two investigations which have been performed on low frequency (LF) sound insulation in buildings at the countryside in Denmark. Both investigations are related to noise from wind turbines but the results can be used in general. The purpose with first investigation - to establish a more precise determination on LF sound insulation in typical houses - was fulfilled due to a mapping in 16 houses/24 rooms, roughly a doubling of the former data. The main conclusion is that LF sound insulation for lightweight holiday houses are approximately 5 dB lower than the average of all other measurements. Houses in the countryside do not have a lower LF sound insulation than Danish houses in general. The purpose with the second investigation was to establish new knowledge on how to improve LF sound insulation in existing Danish houses in areas with wind turbines. This investigation includes: (1) a literature survey to establish existing knowledge, (2) measurements and experiments on 23 building constructions to investigate how to improve sound insulation on heavy and lightweight facades by means of building elements and one experiment using a room acoustic approach, (3) theoretical calculations to evaluate indoor noise annoyance caused by wind turbines in houses - both existing and improved. Some of the conclusions are that it – in some cases – is possible with traditional indoor sound re-isolation or by outdoor façade sound-isolation to improve the LF sound insulation to a degree where indoor LF Wind Turbine noise will be perceived as not-audible or only just audible in a population of people. Also results of measurements on lightweight facades, partly open windows and sound insulation effect on absorbents in the cavity between window frames as well as test-method, -equipment will be presented.

1 Introduction

Indoor noise at low frequencies from Industry, Ferries and Wind Turbines (WT) as examples, can be annoying and sometimes lead to complaints from neighbors. Therefore, the authorities have introduced limit values to regulate the indoor noise at low frequencies. For Wind Turbines, also outdoor limits exist. Based on outdoor noise you must be able to calculate the indoor noise and to do that, you need data for the sound insulation at low frequencies of the buildings. The original data for LF (10-160 Hz) sound insulation in relation to Wind Turbines is based on measurements in 27 rooms in 14 residences. Due to discussions both on WT LF-noise in the press and of these data there has been a request from “Miljøstyrelsen” the Danish Environment Protection Agency (EPA) to increase the underlying data background. A mapping of LF (8-200 Hz) sound insulation in further 24 rooms in 16 houses - as described in [1] - is the topic for the first part of this paper. But you also need knowledge about how to improve LF sound insulation, both in theory and practice, because not all existing building types has the necessary LF sound insulation to reduce indoor LF noise from Wind Turbines to or below the theoretical audibility-limit for a population of people. In some cases, you see that indoor noise levels are higher than outdoor noise levels. Obtaining such new knowledge was the task in another assignment for the EPA - as described in [2]. This is the topic for the second part of this paper. Common for both investigations is the measurement method and -system, which will be described to a start.

2 Measurement method and -system

The measurement method is based on ISO 140-5:1998 [3] and the purpose is to measure the level differences between the outdoor free field sound and the indoor spatial averaged sound field per 1/3 octave band from 8 – 200 Hz without correction for area of test object and absorption area in the receiving room. Also, recommendations from EPA [4] and [5] were used in the planning of the measurement method.

The method in use contains fixed microphone positions: 2 outdoor mics placed directly on the surface of the test object (+6 dB re free field) and 5 indoor mics to limit the room acoustic variance. The sound sources are 2 subwoofers and a broadband loudspeaker placed at the terrain 10 m from the building as shown in Figure 1. Loudspeaker position at terrain is chosen as the most optimal due to earlier investigations from both DELTA Force Technology [6] and Sweco Acoustica [1] – even though one could argue that Wind Turbine noise primarily comes from above, which may have influence in an attic used for living. An elevated loudspeaker position gives around 10 dB lower outdoor signal at important frequencies between 20 and 40 Hz and is therefore not selected.

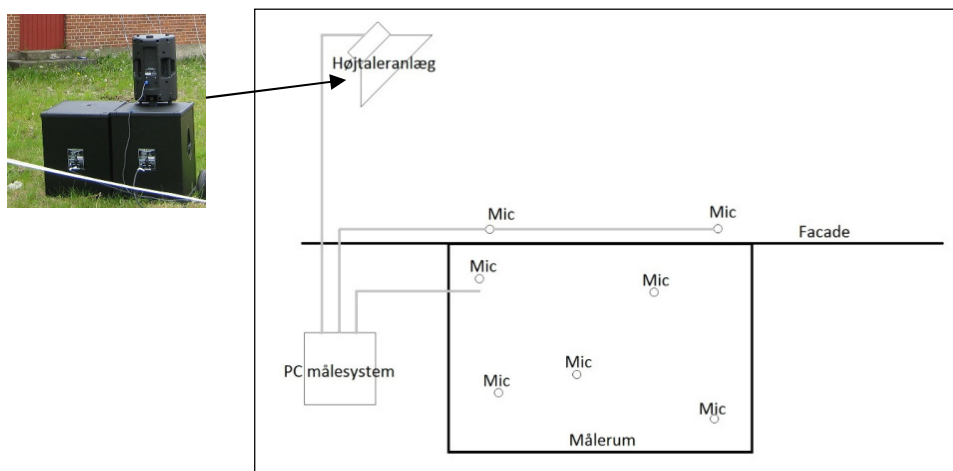


Figure 1. Measurement setup with in- and outdoor mics, PC measurement system and loudspeakers

Compared to real noise from Wind Turbines¹ the loudspeaker setup gives a significantly higher outdoor sound levels at the vertical façade, as shown in Figure 2. Remark that a part of the outdoor noise is below the hearing threshold.

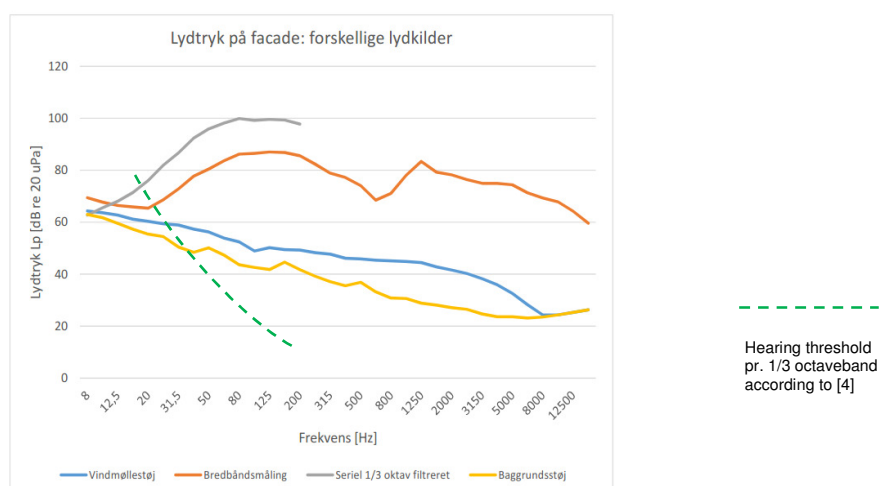


Figure 2. Sound pressure levels from different sources: Wind Turbine and loudspeaker (serial and broadband)

¹ Data from a Vestas V100-2MW Wind Turbine is used with permission from Vestas Wind Systems A/S.

The measurement procedure consists of serial measurements per 1/3 octave 8-200 Hz followed by broadband measurements from 8 to 10.000 Hz, with background noise measurements in between (BGN-serial signals-BGN-parallel signals-BGN). Since background noise at these very low frequencies varies a lot, more repetitions of the measurement series were made. Correction for background noise is made according to [3], and the average level difference is calculated on energy basis. In both reports this average level difference is named “Insertion Loss” (Indsætningsdæmpning) or sound insulation.

3 Mapping of LF sound insulation

The investigation in [1], contains a mapping² of LF sound insulation in 16 houses all situated in Jutland of which focus is laid on elder/typical farmhouses at the country side and summer houses. These types of houses were not included in the original data basis. The investigated summer houses are single-storeyed houses and built of lightweight constructions. The investigated farmhouses are built with heavy walls and with double-pitch roof, most of them with attics used for living. Their roofing varies between heavier tiled roofs to Eternit (fibre cement) plates and more lightweight thin metal plates. Two newer detached houses are also investigated. The one new house had large windows and the other was more classical – both with relatively lightweight roofing. The third new house is the research building at Høvsøre which DTU-Wind (Danish Technical University’s Wind section) was so kind to let us use. All buildings have double-glazed windows. The distribution of measurements in the different building-types and -rooms are listed in Table 1.

Table 1. Number of measurements in different building-types and rooms

Building type (number of these)	Number of measured rooms at the ground floor	Number of measured rooms in the attic
Summer houses (5)	8 rooms	-
Farm houses (8)	6 rooms	5 rooms
New houses (3)	2 rooms	3 rooms
Total (16)	16 rooms	8 rooms
	24 rooms	

As shown there are balance between number of rooms in summer houses and the total number of rooms at the ground floor and in the attic for farm houses and new houses.

3.1 Main results - mapping of LF sound insulation

By grouping the results after building types, it can be seen at Figure 3 that there are some interesting similarities and differences. The similarities are seen when comparing the average of “All new measurements” (Alle Nye målinger) with the average of “Former measurements” (Middelværdi tidligere målinger); only few dB’s differences is seen. The differences are most pronounced for the group “Other rooms in Farm Houses” (Landhuse Andre rum) - i.e. rooms at the ground floor compared to “Lightweight summer houses” (Lette Sommerhuse), where differences up to around 10 dB are seen. Both the curves for the “Attics in the farm houses” (Landhuse tagetage) and “New houses” (Nye huse) have lower and higher sound insulation compared to “All new measurements” at certain frequencies.

² The measurements were performed by several teams from Sweco Acoustica with Jørgen Heiden and Regnar Oxholm Bonde as general acousticians.

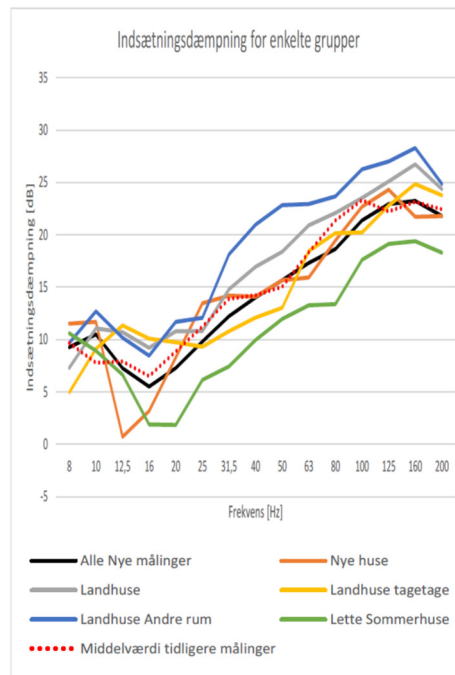


Figure 3. Average values of insertion loss in dB as function of frequency for grouped buildings compared to results of earlier measurements.

In Figure 4 a comparison between the results from the group “Lightweight summer houses” (Lette Sommerhuse), the group “All new measurements exclusive the lightweight summer houses” (Alle nye målinger - lette sommerhuse) and “Average of all earlier measurements” (Middelværdi tidligere målinger) is shown.

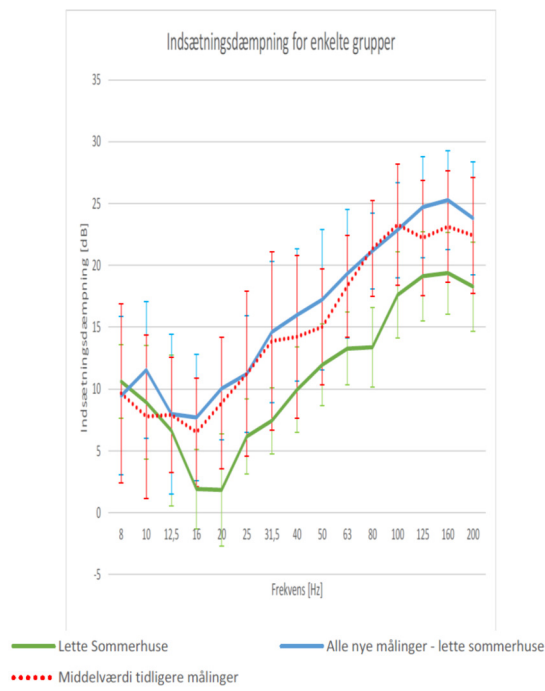


Figure 4. Comparison of insertion loss in dB as function of frequency for three groups of buildings inclusive standard deviation

The curves for “All new measurements exclusive the lightweight summer houses” shows slightly higher values than “Average of all earlier measurements”, but the difference is not significant and the standard deviations are of same magnitude. On the other hand, the difference between “Lightweight summer houses” and the two other curves is around 5 dB at most of the frequencies and at 80 Hz the difference seems to have a statistical significance. At present, it is not possible to compare the data for LF-sound insulation using a single number quantity (i.e. R_w -type and adaption term). Instead you could evaluate the expected indoor LF Wind Turbine noise.

3.2 Indoor LF Wind Turbine noise with the new data

To calculate indoor Wind Turbine noise at the low frequencies in houses a specific method must be used according to an EPA departmental order [7]. The method described in rough terms is a calculation of the outdoor sound pressure level at the façade from a Wind Turbine minus a fixed dataset for level differences at low frequencies. This dataset is based on 67% confidence-levels of the “earlier measurements” mentioned in this paper. According to [7] the A-weighted sound pressure level from Wind Turbines at the façade of a farm house (and outdoor living area maximum 15 m from living houses) at the countryside must not exceed 44 dB. This applies to 8 m/s wind speed measured at 10 m height. To do this calculation you need a sound power spectrum from a typical Wind Turbine. The distance from the house is chosen to be 500 m and the hub-height 90 m. The LF-corrections for terrain and air-absorption are according to [7]. The standardized sound-power spectrum for a typical Wind Turbine is given in [8] and shown in Table 2.

Table 2. Standardized sound-power spectrum for Wind Turbines above 2MW.
The spectrum is A-weighted and normalized to $i = 0$ dB re 1 pW.

Frekvens [Hz]	10	12,5	16	20	25	31,5	40	50	63	80	100	125	160
$L_{WA, 1/3 \text{ oktav}}$ [dB]	-61,2	-55,7	-49,5	-44,3	-39,1	-35,3	-31,2	-27,5	-24,4	-20,4	-18,6	-16,7	-15,8
Frekvens [Hz]	200	250	315	400	500	630	800	1000	1250				
$L_{WA, 1/3 \text{ oktav}}$ [dB]	-14,7	-13,1	-12,1	-12,1	-10,5	-10,7	-10,8	-10,8	-11,4				

Based on this information it is possible to calculate $L_{pA,LF}$, the indoor A-weighted sound pressure level at low frequencies from 10 to 160 Hz. To simplify the presentations of the results of the new measurements, the earlier measurements of level differences from [7] is used as reference, as shown in Table 3.

Table 3. Expected indoor A-weighted LF Wind Turbine noise, $L_{pA,LF}$ in dB re 20 μ Pa with earlier measurements and 67% confidence levels as references. Negative values mean higher sound insulation and positive values lower sound insulation compared to earlier measurements.

Building type	Indoor Wind Turbine LF sound pressure level re level-differences from earlier measurements, $L_{pA,LF}$
Earlier measurements	0,0 dB
Farm houses (all measurements)	-1,6 dB
Farm houses used attics	0,5 dB
Farm houses – other rooms	-3,7 dB
New houses	0,6 dB
Lightweight summer houses	4,5 dB
All new measurements	1,1 dB
All measurements	0,5 dB
All measurements excl. lightweight summer houses	-0,4 dB

Conclusions: The old and the new dataset excl. summer houses are similar, but the summer houses have around 5 dB lower sound insulation than the average of all other measurements.

4 New knowledge on improving LF sound insulation in existing houses

In this part, you find a description on the second investigation, see [2], containing a literature survey, measurements and experiments on existing building constructions plus one room acoustic and finally a theoretical calculation on indoor LF noise annoyance caused by wind turbines in the houses.

4.1 Literature survey

The introductory literature survey³ gave a somewhat sparsely output, even though questionnaires were sent to 65 acousticians⁴ in 17 countries. Out of 57 reports, articles and papers only 14 were about sound insulation at frequencies from 10 to 160 Hz and other 14 on frequencies above 50 Hz. The investigation showed that it is mainly in Denmark you find data for sound insulation in the frequency interval 10-160 Hz. But also from Norway you find investigations on noise and vibrations - from military activities (overflights and explosions) - down to 10 Hz, and here it is found that noise transmitted through roof and façade generates vibrations in the floor and that air-tightness plays an important role. Further you find Norwegian lab-measurements on facades, windows, roofs and outdoor air-inlets down to 50 Hz and a few on facades down to 31,5 Hz. From Japan is found a house-filter method based on 22 Japanese wooden houses and 2-3 types of windows, which has good agreement with the sound insulation data in [7]. From the USA is found a newer project on simulating indoor noise levels from Wind Turbines based on a model for supersonic airplanes. The conclusion is among other things that indoor noise levels can be higher than the outdoor levels due to resonances at low frequencies. Also, publications from USA on sound insulation of windows down to 50 Hz were found. From Germany was found three references about sound insulation of facades and roof, among these many as wooden constructions – including outside thermal insulation, down to 50 Hz related to road traffic noise. From Belgium likewise works on façade-designs was found on sound insulation down to 50 Hz. From Canada sound insulation lab-measurements was found on lightweight façade- and roof-constructions down to 50 Hz. Swedish and English literature have focused on the importance on room-modes in the receiving room using FEM-analysis on the wall's sound insulation at low frequencies. Also, examples on the influence from resonances in the building elements cavity was found. From Italy was found papers on uncertainties on LF sound insulation measurements on facades. From Switzerland was found research in low frequency sound insulation in windows using tuned resonators. Among the main outcomes of the literature survey are the importance of using thick windows to ensure good LF sound insulation and that outdoor thermal insulation should not be forgotten as means of improving the LF sound insulation. Further, that more attention perhaps should be paid on air-tightness.

4.2 Measurements and experiments on improving LF sound insulation

First task was to find a representative building in which we were allowed to make experiments which included mounting of new building elements. To do that we first performed another survey on the typical constructions-types in existing 1147 buildings on the countryside near Wind Turbines. We found, that in more than 50% of the farm houses the attic were used for living and under 50% had roof with Eternit (fibre cement) or heavier tiled roofs or roofs with cement-stone. In more than 90% the façades were made of bricks. Fortunately, we found such a house in Nibe, northern Jutland, see Figure 5 in which we could make all the experiments we could wish without reestablish requirements. The Danish section of Vattenfall Vindkraft A/S, was so kind to let us use this building, because they had bought some farm houses that now just waited to be demolished. Some of these houses had already been used in the first investigation [1], described in section 3, Mapping of LF sound insulation. The building we would use had facades of bricks and roof of Eternit (fibre cement). Because we wanted both to make experiments with heavy and lightweight constructions we could here use the ground floor as the “heavy site” and the first floor as the “lightweight site”. Another reason to just use one building was to limit the initial reestablishment work since the buildings were condemned and some façade windows and doors were removed – to avoid foreigners to occupy the buildings. The company Saint Gobain's section Gyproc and Isover were very kind to sponsor both gypsum plates, steel profiles as well as systems for outdoor façade insulation inclusive plaster and the large quantities of glass wool.

³ The literature survey is performed by Dan Hoffmeyer from DELTA Force Technology

⁴ From the surface of contact of Birgit Rasmussen from The Danish Building Research Institute (SBI) – Aalborg University



Figure 5. Photo of the building before the experiments on improving LF sound insulation

The general plan for the experiments were to test practical insulation methods that were efficient at the low frequencies. The traditional mechanisms are enhancing 1) surface-weight 2) stiffness 3) thickness and 4) separating inner and outer parts of the building construction. These mechanisms are *passive* and use supplementary or changed building elements. No experiments with unconventional resonators included in the cavities of the building were performed. Neither the *active* electronic systems such as active noise control using mics, loudspeakers and DSP. A third method with LF-damping of the room acoustics was tested. Because we only test level differences it makes sense to test to how much reduced reverberance will improve the indoor LF sound pressure level. Basically, the experiments were performed in 3 sections, A) improvement of heavy constructions, i.e. indoor linings/window and outdoor linings, B) improvement of lightweight constructions, i.e. indoor linings and C) improvement of the LF-room acoustics. During the experiments also check of the flanking transmission to - and the importance of openings in - the receiving rooms were performed. The main results are described in the following section.

4.3 Main results - improving LF sound insulation

To compare all measurements and their matching spectra may be confusing as can be seen at Figure 6. Remark the negative sound insulation at 10 Hz – maybe caused by a resonance ($f_{1,1}$) in the thermo-pane in the existing window.

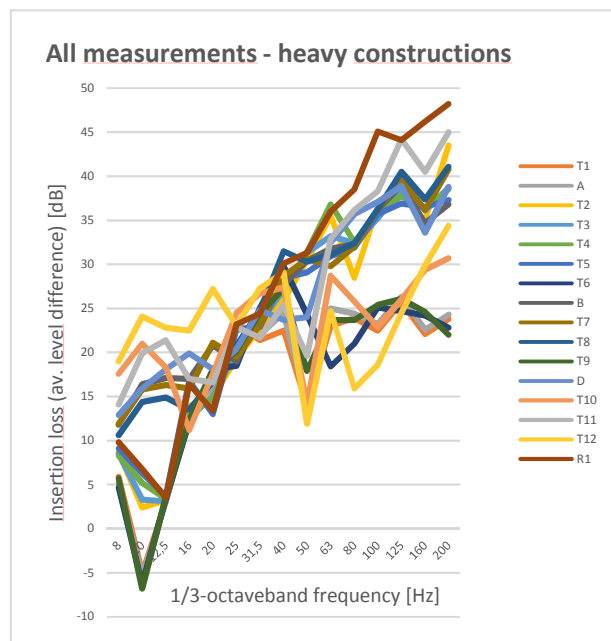


Figure 6. All measurements from experiments on heavy constructions

Therefore in the following description of experiments only a few spectra will be shown in the presentation of the results which is simplified using the method from section 3.2 to calculate indoor Wind Turbine noise at the low frequencies $L_{pA,LF}$ in houses. This means, that the indoor sound pressure level is calculated based on the LF sound insulation from the different building constructions, using a fixed outdoor Wind Turbine noise spectrum and -level fulfilling the EPA requirements. Remark the EPA's indoor threshold limit for LF-noise in houses is $L_{pA,LF} \leq 20$ dB.

4.3.1 A: Heavy façade constructions

One of the first experiments was to test increased stiffness of a free-standing lining. The result was not convincing - only at one 1/3 octave band, 63 Hz you got a 5-dB improvement. Other experiments were test of the improvement achieved with a free-standing lining (3 x 13 mm gypsum plate and 300 mm, dampened cavity) with a heavy removeable window (10 mm single pane) compared with a lining closer to (150 mm) - and with "sound bridges" to - the original façade. As can be seen in Figure 7, the indoor LF Wind Turbine noise with the existing façade and the normal double-glazed window is $L_{pA,LF} = 13$ dB, which fulfills the EPA requirement on max. $L_{pA,LF} = 20$ dB. Using the two types on lining improves $L_{pA,LF}$ with 11 and 10 dB.

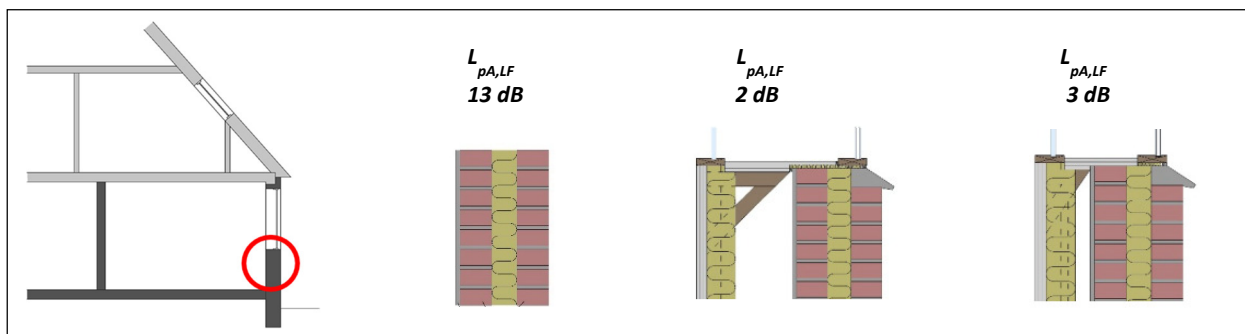


Figure 7. $L_{pA,LF}$ from Wind Turbine and improvements by means of linings with a heavy removeable window

The frequency dependence for the same constructions are shown in Figure 8, where it is interesting to see the small difference between the effect of the two linings. Also, experiments were performed with sloped removeable window and absorbents in the cavity between existing and removeable window along the frame. Both had minor effects, at some frequencies even negative. At these low frequencies, it is not recommended to use sloped glass or absorbents in the cavity between windows.

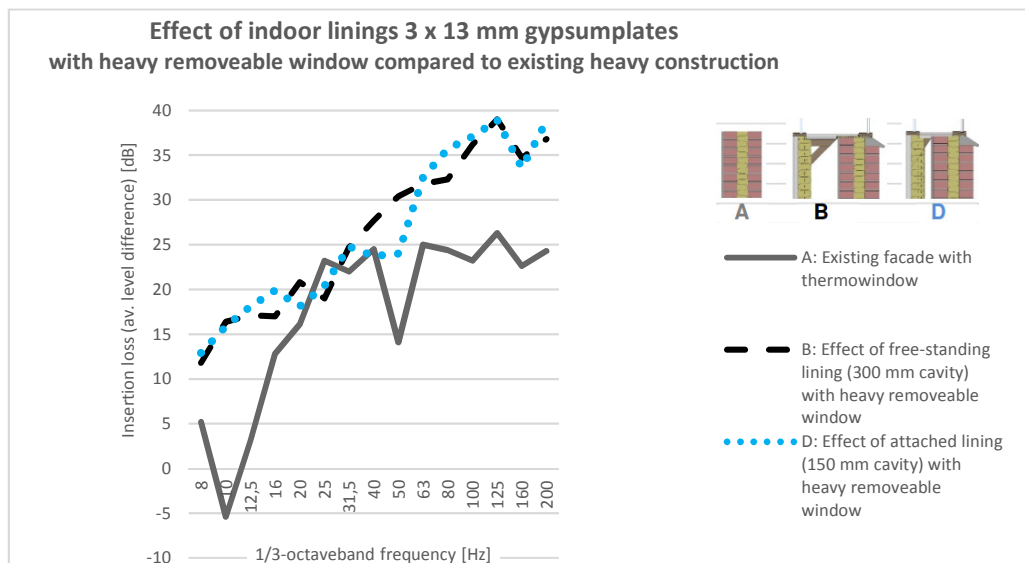


Figure 8. Sound insulating effect of linings (B: free-standing and D: attached) incl. heavy removeable window compared to A: existing heavy façade and window.

To investigate the effect of outdoor façade insulation - which originally was invented for thermal insulation - two experiments were performed. One with glass wool insulation and plaster (named F in the following) and another with glass wool insulation and gypsum plates plus plaster (named E in the following). The results are shown in Figure 9, where it is seen that the outdoor façade insulation with glass wool insulation and gypsum plates plus plaster improves $L_{pA,LF}$ with 6 dB.

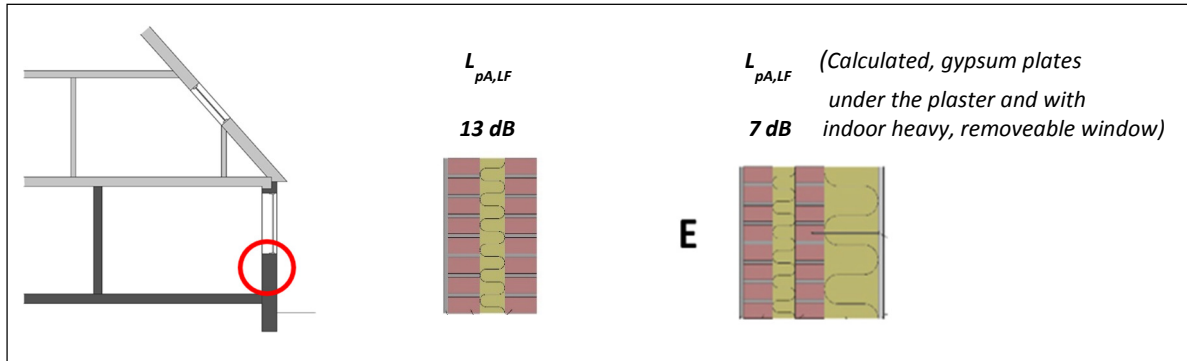


Figure 9. $L_{pA,LF}$ from Wind Turbine and improvement by means of outdoor lining inclusive a heavy removeable window – heavy façade constructions

How indoor and outdoor isolating works are shown in Figure 10, where it is seen that the LF sound insulation for the outdoor isolation system with the plates (E) in nearly all frequency bands is only 3-5 dB lower than the indoor isolation with sound bridges (D). By comparing Figure 7 and Figure 9 you see that the difference in $L_{pA,LF}$ between E and D is 4 dB. Comparison of the two types of outdoor isolation shows that the outdoor isolation system covered with the plates and plaster (E) is the most efficient concerning LF sound insulation compared to the system covered only with plaster (F). Calculations show that $L_{pA,LF}$ is rising(!) with 3 dB due to the low level differences at 80 and 100 Hz for solution F.

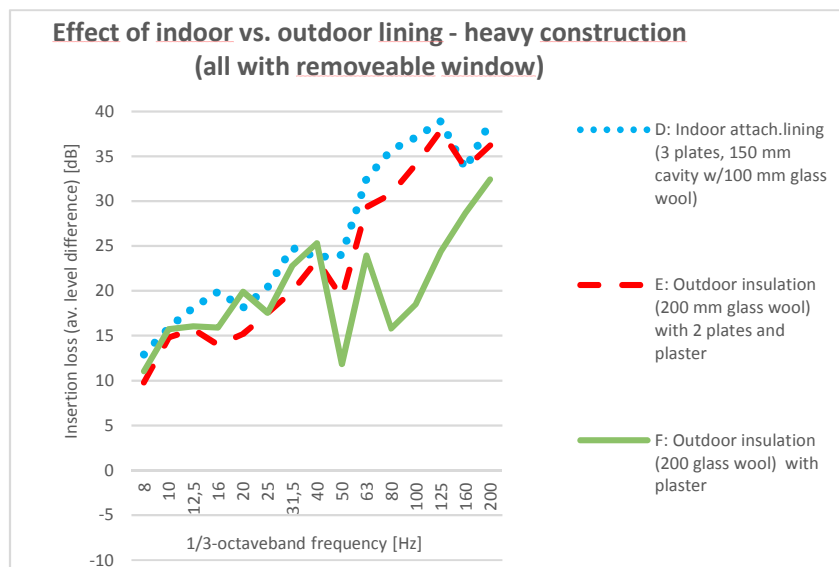


Figure 10. Comparison of LF sound insulating effect of indoor (D) and two outdoor isolation systems (E and F) on a heavy construction.

4.3.2 B: Light weight constructions

Concerning lightweight constructions, a number of experiments were performed. First of all, it was necessary to improve the sound insulation via the flanking – or indirectly - soundpaths to the receiving room in the attic by adding extra gypsum plates to the internal walls. Then several tests were performed including the existing ceiling, sloping wall and the vertical wall separating the space under the roof (named G in the following). Then a free-standing lining: 3 x 13 mm gypsum plates, 150 mm cavity with 100 mm glass wool in front of the existing construction were measured (named K). After that

3 x 13 mm gypsum plates directly mounted to the existing construction (named J) and finally after demounting the existing inner constructions new inner construction with 3 x 13 mm gypsum plates and larger, 200 mm cavity on new rafters with 100 mm glass wool in the cavity with were measured (named H). The results given as $L_{pA,LF}$ are shown in Figure 11, where it appears, that the existing construction (G) just only fulfills the EPA requirement on max. $L_{pA,LF} = 20$ dB. The best improvement on $L_{pA,LF}$ is 7 dB is established with the free standing lining (K). Surprisingly the simple added gypsum plates (J) gives the same improvement on $L_{pA,LF}$ on 5 dB as the complex construction with demounting the existing inner construction and expanded cavity (H).

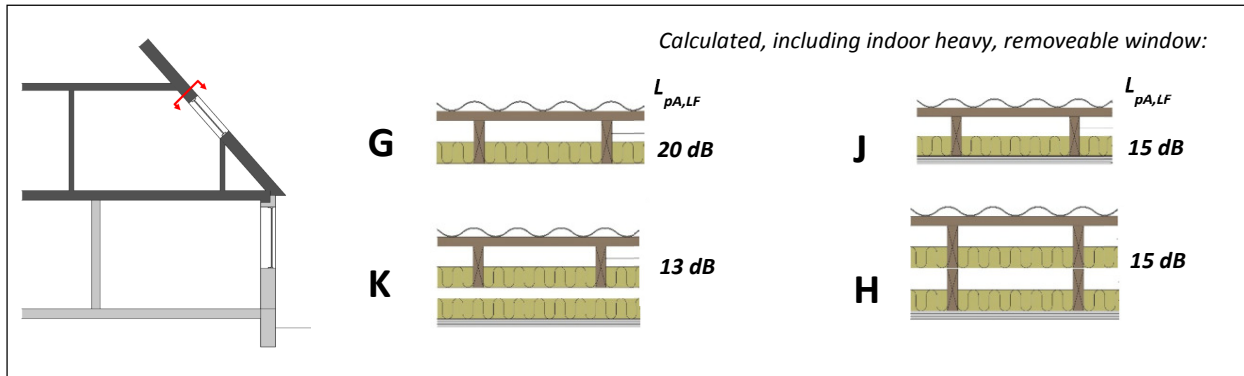


Figure 11. $L_{pA,LF}$ from Wind Turbine at G: existing lightweight constructions and measured/calculated improvements by means of indoor linings inclusive a heavy removeable window. K: Free-standing lining, J: Directly mounted gypsum plates under existing ceiling, H: Expanded cavity.

The effect of number of gypsum plates was tested on the free- standing lining (similar to K above, but without removeable window). The measurement results as function of frequency are shown in Figure 12, where it appears, that in the important frequency area from 40-100 Hz it makes good sense to use the heaviest lining (here 3 layers of gypsum plates).

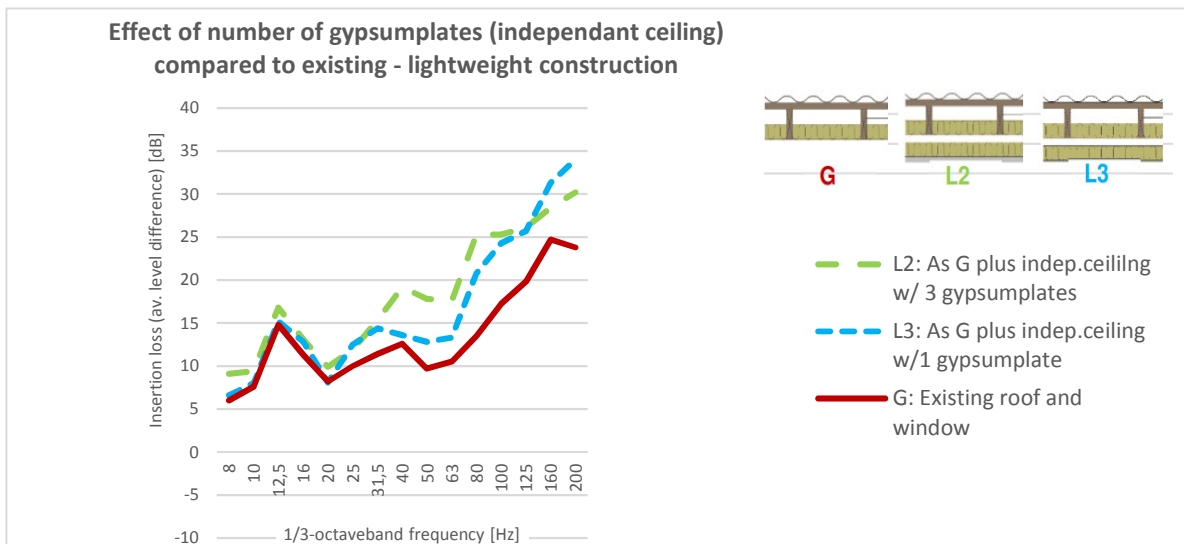


Figure 12. Effect on LF sound insulation of number of gypsum plates (1 plate in L3 and 3 plates in L2) on a free-standing lining in front of a existing lightweight construction (G).

Concerning openings, two measurements were performed. One with a minor opening (air-inlet $\varnothing=100$ mm) in the heavy façade construction. Only at two 1/3 octave bands, 40 and 63 Hz you see a minimal negative effect on 2 dB due to the small opening. The normal R'_w value (defined in the building acoustical frequency area 100-3150 Hz) was - as expected - reduced due to the opening with around 6 dB. Actually, the negative effect was only at frequencies above 400 Hz. The other opening was a window in the roof, 50 mm opened (approx. slit-length 660 mm) which showed significant negative effects up to more than 10 dB at frequencies below 16 Hz and above 160 Hz. Some of the complaints of LF WT indoor noise may be caused by people sleeping with partly open windows.

4.3.3 C: Room acoustic measures

A single experiment was performed to investigate a room acoustical approach. The idea was to increase the amount of LF absorption in the receiving room at the heavy façade and by that reduce the sound pressure level. The LF absorption was established by means of absorbing columns of glass wool placed in all corners of the room. The room acoustical experiment was performed in an empty receiving room with an indoor free-standing lining placed in front of the façade. The lay-out and effect as function of frequency is shown in Figure 13. From approximately 50 Hz and upwards you see that the LF-absorbents gives an increasing damping.

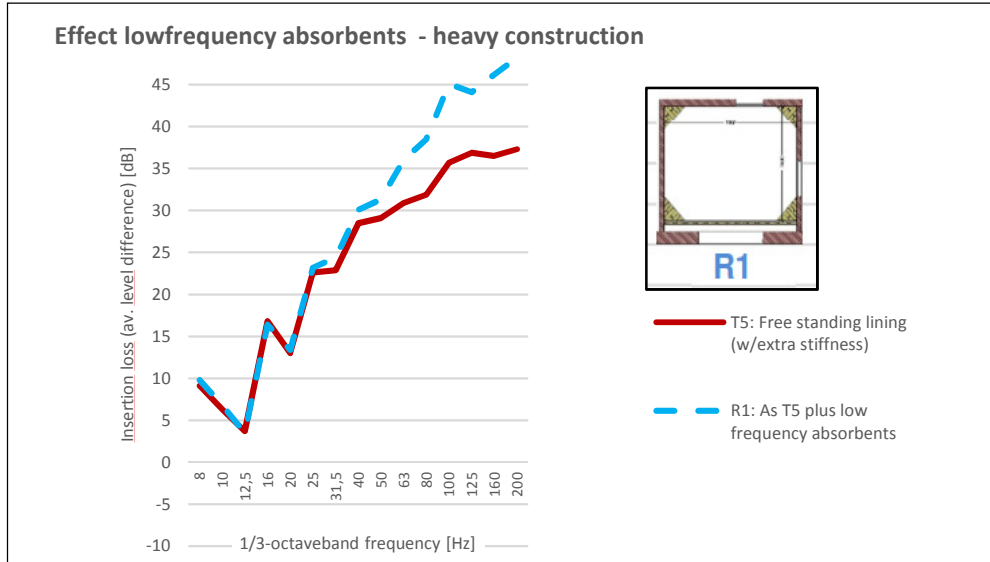


Figure 13. Effect on the LF sound insulation using LF absorbents (R1) in a receiving room with an indoor free-standing lining propped up (T5) 300 mm from the heavy façade.

If this damping effect is combined with a heavy removeable window, it can be calculated that the indoor LF Wind Turbine noise level $L_{pA,LF}$ is improved (lowered) approximately 4 dB due to the LF absorbers. This is an absolute maximum value for improvement because the reference situation without LF absorbers is a+ quite empty room, which will not be the case in real life situations.

4.4 Indoor noise annoyance

The annoyance for 11 indoor Wind Turbine noise spectra transmitted to the receiving room – via facades with windows – is evaluated in terms of audibility and clearness in a report by DELTA / SenseLab⁵ in [9]. The indoor spectra are evaluated according to three methods: 1) Audibility of broadband LF noise near the threshold, 2) Loudness and loudness-level calculated by means of the Zwicker-method and 3) Evaluation of Spectral balance. The 11 spectra are named A-K and represents the existing conditions (A, G) as well as the results of several measured (B, D og I) and calculated (C, E, F, H, J og K) improvement experiments. All evaluations of audibility are performed based on an assumption of absence of noise from other sources. This means that wind generated noise in vegetation and buildings are ignored. This situation is like a worst case, where a house is exposed by the highest allowed noise level downwind from Wind Turbines a quiet night. One of the remarks in the evaluation is that the frequency components which contributes most to the level in the lowest critical band (10-80 Hz) in the indoor Wind Turbine noise – after threshold weighting – are in the region 50-80 Hz. This observation plays down the role of the very low frequencies - below 50 Hz - at least for these indoor spectra. Figure 14 shows all hearing-threshold-weighted spectra and the results of the audibility evaluation, which is also supported by the Zwicker calculations (defined from frequencies 25 Hz and above). It must be emphasized that “audibility” in this context refers to theoretical calculations based on hearing thresholds for a population of people which causes that single persons may be able to hear the LF noise. In this case the spectra become audible when $L_{pA,LF} > ca. 10$ dB and $L_{Aeq} > 7-8$ dB.

⁵ The annoyance evaluation is performed by Torben Holm Pedersen from DELTA / SenseLab

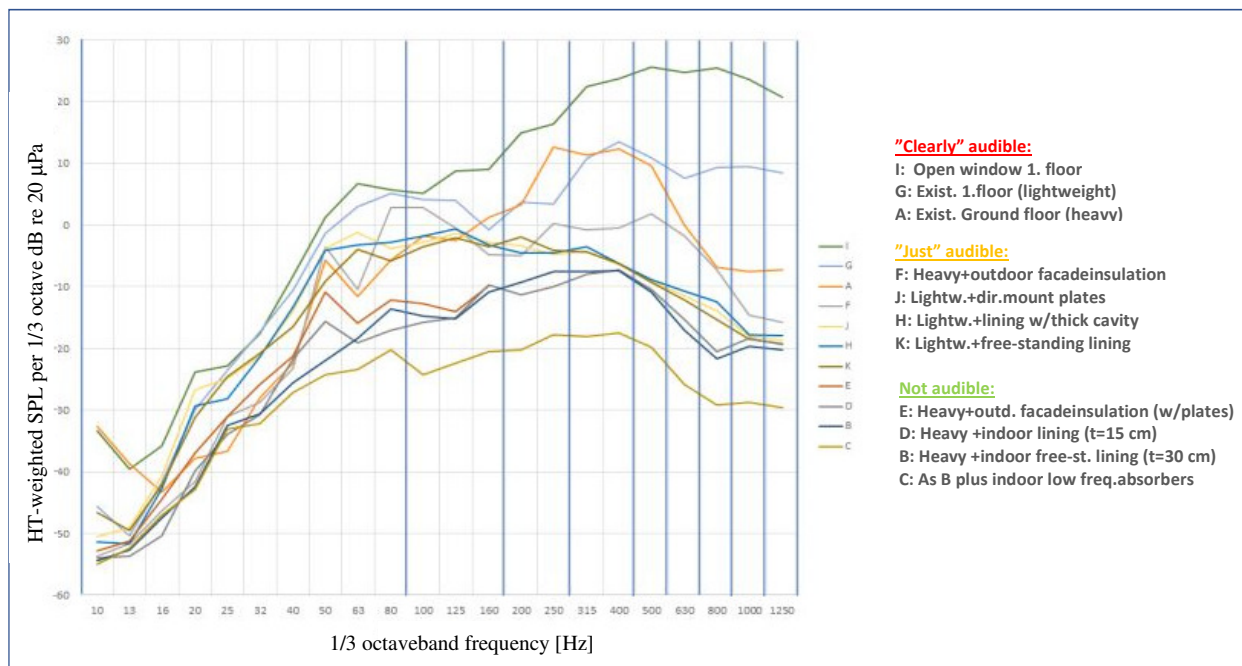


Figure 14. Indoor WT noise 1/3 octave spectra, hearing threshold-weighted and sorted with declining A-weighted level top-down. The vertical blue lines show the limits for the critical bands.

In the reports section on evaluation of Spectral Balance, it is shown that all the unweighted spectra except A and I are sloping more than 5 dB/octave (increasing against lower frequencies). For ventilation noise, it is mentioned that a noise spectrum which is falling more than 5 dB above 31,5 Hz is assumed to be rumbling/booming. Due to the lower level and different characteristics for indoor Wind Turbine noise compared to ventilation noise the report makes some reservations for the relevance in the actual case. All in all, the evaluation of the perceived indoor noise from Wind Turbines shows that it is expected to be audible for most people under existing conditions both behind the heavy and the lightweight facades. The evaluation also shows that it is possible – in some cases – to reduce LF the noise to a degree which for a population of people will be just audible or even not audible with the tested LF sound isolating measures. All evaluations are based on that no low frequency background noise is present.

5 Summary

On sound insulation at low frequencies (LF) the first of the two investigations described in this paper shows that the existing data basis in the Danish EPA Departmental Order also applies for farm houses at the country side but not for lightweight summer houses, which have approximately 5 dB lower LF sound insulation. The standard deviation for new and old measurements are of same magnitude. The second investigation shows that both for heavy and lightweight façades you can achieve significant improvements of the LF sound insulation. For the heavy façades, you can reduce the indoor LF Wind Turbine (WT) noise to become inaudible for a population of people with relatively simple means, e.g. indoor gypsum-linings with sound bridges and small distances (approx. 150 mm) to existing walls and a heavy removeable window. But also, outdoor thermal isolation plus the heavy removeable window can reduce indoor LF, WT noise to become just audible for a population of people. By using outdoor thermal isolation which includes plates behind the plaster it is possible to reduce indoor LF, WT noise as much as using the indoor linings. There is no improving effect on the LF sound insulation by using sloped removeable windows or absorbers in the cavity between this and the existing window. With the investigated indoor isolation means, the lightweight constructions can be improved so the indoor LF, WT noise to becomes just audible for a population of people. For the lightweight constructions, also simple means as attaching extra gypsum plates on the internal surfaces (ceiling, sloped walls etc.) has an effect comparable with more complicated remedies. It is though necessary to use more layers of gypsum plates and to ensure that indirectly/flanking sound paths also are dampened. The terms “just audible” or not audible” – for a population of people – does not guaranty that any single person can’t hear the LF noise. It must be emphasized that open windows are destructive for the sound isolation also at low frequencies and that ventilation thereby must be provided by other – sound isolated – means. Future work could be to develop single number quantities for LF WT noise to simplify comparison between constructions.

References

- [1] B. Søndergaard, (in Danish) Expanded databasis for sound insulation against noise at low frequencies in Danish houses “Udvidet datagrundlag for danske boligers lydisolations mod lavfrekvent støj”, *Miljørapport nr. 1866*, ISBN 978-87-93435-82-7, Miljø- og fødevareministeriet, Miljøstyrelsen, København, 2016.
<http://mst.dk/service/nyheder/nyhedsarkiv/2016/jun/udvidet-datagrundlag-for-danske-boligers-lydisolation/>
- [2] C. M. Petersen, (in Danish) New knowledge on sound insulation at low frequencies of buildings in areas with Wind Turbines “Ny viden om lavfrekvent lydisolations af boliger i områder med vindmøller”, *Miljøprojekt nr. 1960*, ISBN 978-87-93614-27-7, Miljø- og fødevareministeriet, Miljøstyrelsen, København, 2017.
<http://mst.dk/service/nyheder/nyhedsarkiv/2017/okt/ny-viden-om-lavfrekvent-lydisolation-af-boliger/>
- [3] DS/EN ISO 140-5:1998, Acoustics – Measurement of sound insulation in buildings and of building elements – Part 5: Field measurements of airborne sound insulation of façade elements and façades, *Dansk Standard*, København 1999
- [4] Miljøstyrelsen, (in Danish) EPA, Lowfrequency noise, infrasound and vibrations in the external environment, “Lavfrekvent støj, infralyd og vibrationer i eksternt miljø”, *Orientering nr. 9*, Miljøstyrelsen, København, 1997
- [5] Miljøstyrelsen, (in Danish) EPA, Erratum to [4] part 3.4.1 Measurement positions “*Rettelsesbrev vedr. afsnit 3.4.1 Målepositioner i [4]*”, Miljøstyrelsen, København, 1997
- [6] DELTA Akustik og Vibration, (in Danish) Measurement of sound insulation in the low frequency area. Analysis of the significance of the placement of the outdoor loudspeaker, “Måling af lydisolations i lavfrekvensområdet. Analyse af betydningen af udendørshøjttalerens placering”, *TC-100847*, Hørsholm, 2015
- [7] Miljøstyrelsen, (in Danish), EPA Departmental order on noise from Wind Turbines no. 1736 “*Vindmøllebekendtgørelsen Bekendtgørelse om støj fra vindmøller nr. 1736 af 21/12/2015*”. Miljøstyrelsen, København, 2015
- [8] B. Søndergaard, Low frequency Noise from Wind Turbines: Do the Danish Regulations Have Any Impact? An analysis of noise measurements. *International Journal of Aeroacoustics* Volumen 14 number 5&6, page 909-215, 2015
- [9] T. H. Pedersen, (in Danish) Evaluation of noise annoyance from indoor Wind Turbine noise spectra, “Vurdering af genevirkning af indendørs vindmøllesøjspektre”, *TC-101073, DELTA / SenseLab*, Hørsholm 2017