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A Note on the Debate about Health Effects from Low Frequency Noise (LFN) from Modern Large Wind Turbines

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Abstract

There is an intense debate between proponents and opponents of wind turbine projects on the subject of health effects from LFN attributable to modern wind turbines. Opponents, using mainly early 1970's reports from obsolete-design downwind-turbine models, declare excess LFN to exist and to be a suspect cause of adverse health effects. Proponents point to the fact that there is no credible evidence showing LFN from wind turbines to have any adverse health effects.

Hessler Associates has been a technical consultant on more than 60 wind projects with the primary duty of drafting Noise Assessment Analysis for project developers. We, and I might add most opponents of wind projects, are certainly not qualified as experts in the subject of health effects from LFN. In our capacity, the LFN debate is addressed by referencing studies performed by qualified scientists in the field. However, while not health experts, we can apply engineering measurements, logic and common sense to form an opinion on the subject as described in this note.

Introduction

One can address the LFN debate by answering the following three questions:

- How much LFN noise is created by modern wind turbines?

What pressure spectra attributable to wind turbines occurs both outside and inside residences near wind projects?

- Are the pressure levels at residences excessive based on scientific evaluations and comparison to other LFN sources?

Wind Turbine Sound Power

Figure 1 below plots the measured apparent A-weighted sound power spectra from 78 wind turbines ranging in capacity from 75 kW to 3.6 MW[1]. Measurements were carried out down to 4 Hz in some cases. Electrical tones associated with the generator show up at 50 and 60 Hz.

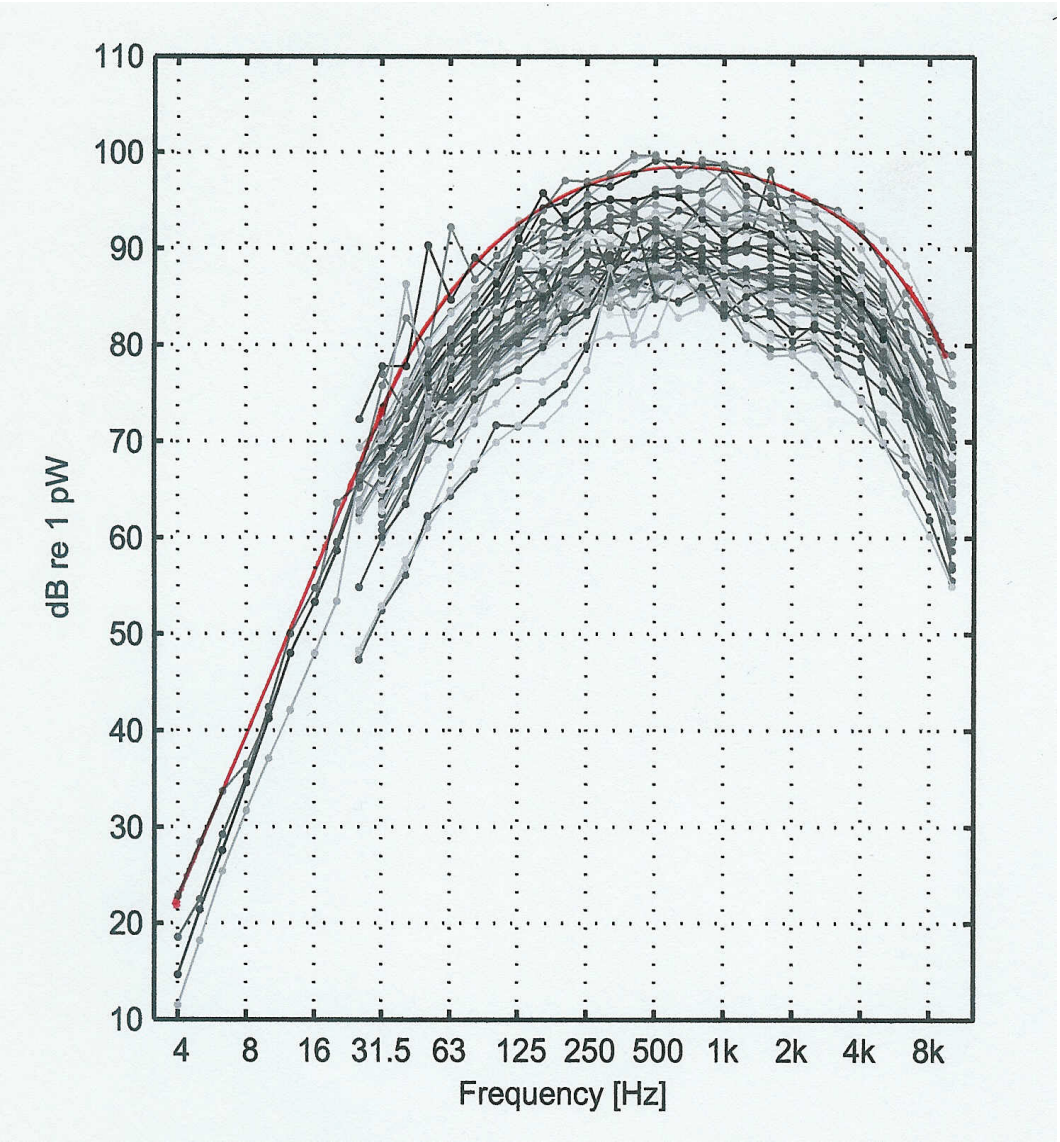


Figure 1

The red overlay was drawn by the author to represent the sound power for the largest wind turbines in use today**.** **Figure 2** shows the computed A, C and Z weighted overall levels and 1/3 octave spectra for this overlay.

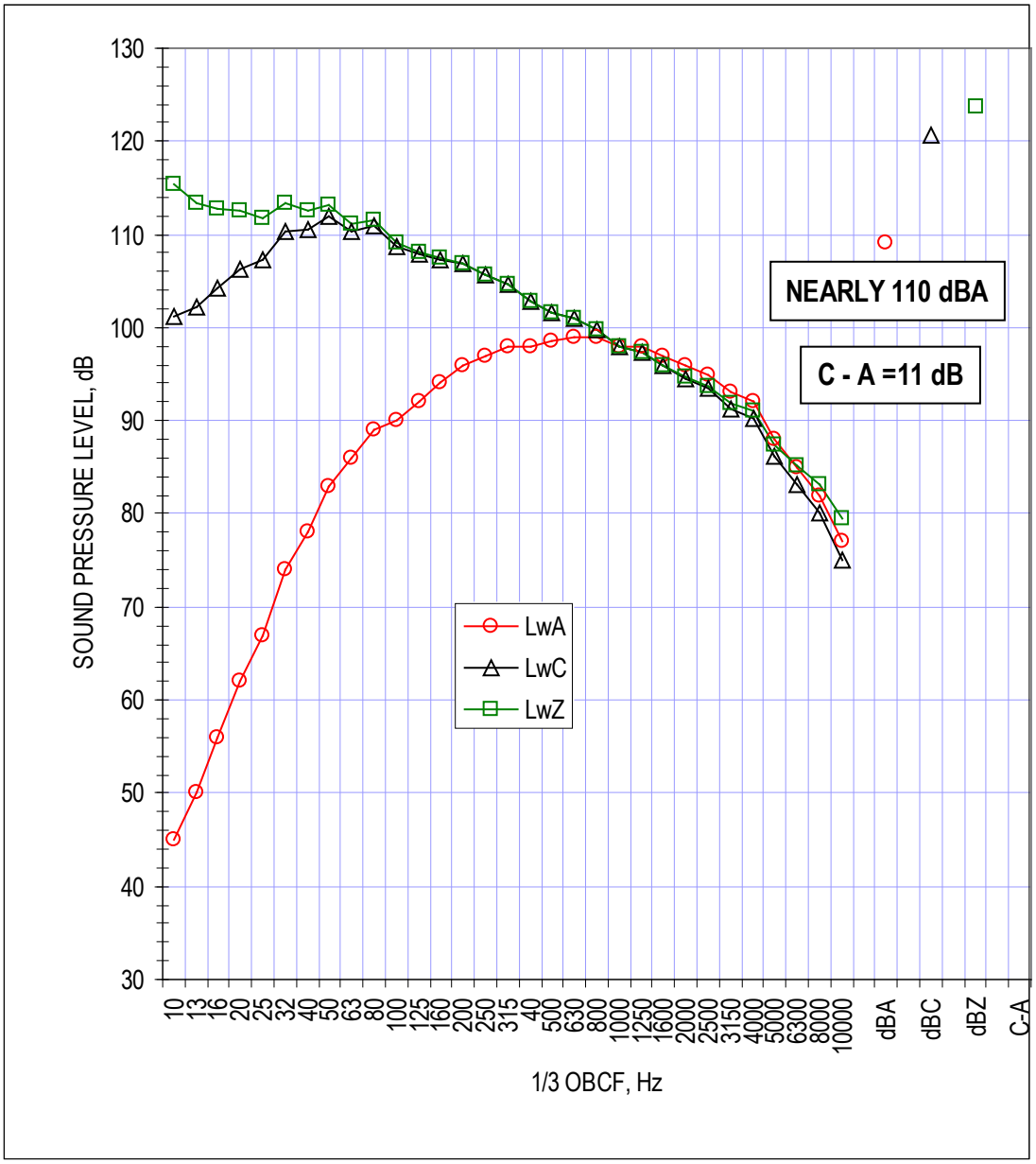
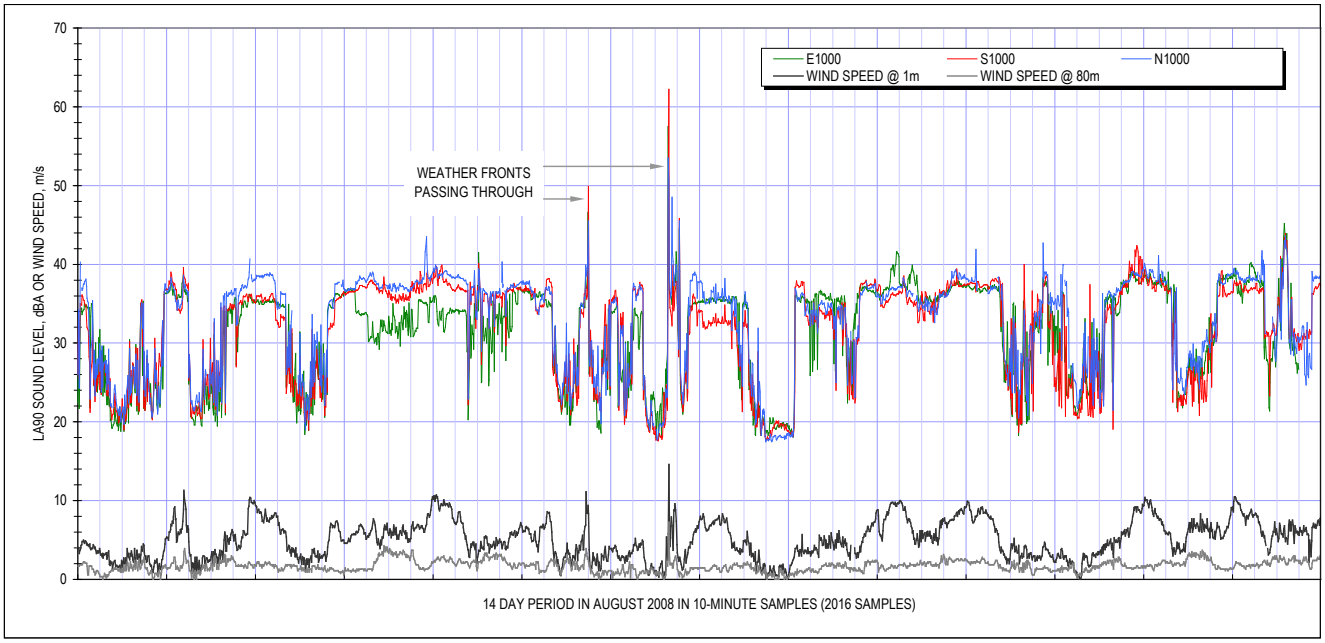


Figure 2

The overall A-weighted level of nearly 110 dBA, re. 1 pW agrees well with specific data from recent large turbine projects. The C-A quantity of 11 dB is the first indicator that large wind turbine spectra are not dominated by the low frequency range. The threshold to determine LFN dominance in a spectrum is typically 15 to 20 dB level difference.

Wind Turbine Pressure Spectra at Residences

Pressure spectra at residences attributable to wind projects is a highly variable with time, whereas measured spectra at the IEC test distance of one hub height plus ½ the rotor diameter is almost perfectly steady with time. This of course is due to atmospheric effects and the very nature of natural wind. To illustrate, **Figure 4** below plots the long term A-weighted LA90 (10 minute) overall level over a 14-day sampling period. The data is for three equal directions of 300 m for a single turbine located at the end of a line of turbines about 300 m apart. Hence, we have upwind, downwind and directional variability as well as the unsteadiness of the wind source. The area is very quiet large farm farmland with typical background sound at about 20 dBA during low wind periods.

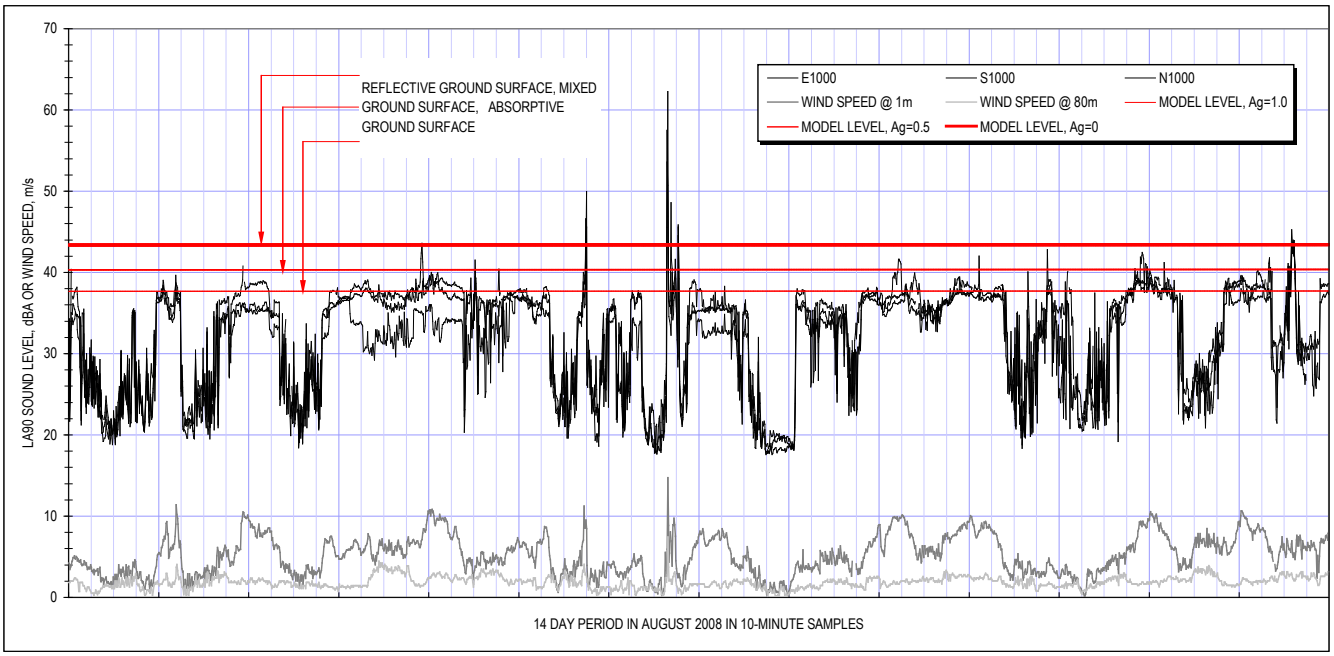


RAW DATA AT 1000' IN THREE DIRECTIONS WITH WIND SPEED AT 1m AND 80m

Figure 4

How do we model such a moving target to get the correct answer? In our repeated experience, using the relatively simple algorithms of ISO 9613, part 2 that does not account for any atmospheric instability gives surprisingly representative results. The wind turbine is modelled as an omni-directional point source at hub height using the measured downwind sound power determined by IEC 61400-11. Ground surface effects are the major variable for typical wind projects without complex topography. **Figure 5** re-plots the above data with ISO 9613 model results for the range of ground absorption between 0 and 1. The ground in this example was a planted soybean field with plants about 400 mm high that would suggest a ground effect input of between 0.5 and 1.0.

Figure 5 shows that an input of 0 is clearly too conservative but an input of 0.5 gives a very representative and slightly conservative prediction of long term wind turbine noise and even an input of 1.0 is correct for substantial time periods.



RAW DATA COMPARED TO ISO 9613 PREDICTION ALGORITHMS

Figure 5

Now that we have a useful model we can calculate the pressure spectra for representative modern day large wind projects using the sound power developed in the first section. The ISO 9613 calculation and plot of the indoor and outdoor spectra results are given below in **Figure 6**.

The distance chosen and additive correction were chosen to result in a wind project sound level of 45 dBA outside of the closest residences. We recommend a design goal of 40 dBA and a regulatory limit of 45 dBA to clients and receptors to minimize audible impact based on our detailed journal article[2]. Therefore, the spectrum is representative of the higher level for a well designed project based on our experience.

CALCULATE Lp AT:	750M	PER ISO 9613, PART 2												
		16	31	63	125	250	500	1k	2k	4k	8k	dB(A)	dB(C)	C-A
MAXIMUM UNIT SIZE SOUND POWER		118	117	117	113	111	107	103	100	95	88	109.2	120.6	11.5
PATH ATTENUATION:														
HEMISPHERICAL SPREADING, R,feet=	2460	-65	-65	-65	-65	-65	-65	-65	-65	-65	-65			
DIRECTIVITY, 0-110 DEG.(HAI), ANGLE=	NONE	0	0	0	0	0	0	0	0	0	0			
AIR ABSORPTION,59F(15C) 50%RH, R=	1	0	0	0	0	-1	-2	-3	-8	-27	-96			
NUMBER OF IDENTICAL SOURCES=	4	6	6	6	6	6	6	6	6	6	6			
ISO GROUND EFFECTS-D,Hs,Hr,ABS=	0.5	0	0	0	-3	-2	-2	-2	-2	-2	-2			
MISCELLANEOUS		0	0	0	0	0	0	0	0	0	0			
MISCELLANEOUS		0	0	0	0	0	0	0	0	0	0			
SUM OF PATH ATTENUATION:		-60	-60	-60	-63	-62	-63	-64	-69	-88	-157			
CALCULATED OUTSIDE Lp PER ISO 9613.2 @	**750M**	**58**	**58**	**57**	**50**	**48**	**44**	**39**	**31**	**7**	**-69**	**45.5**	**60.2**	**14.7**
EST.CONSERVATIVE O TO I NR (CLOSED WINDOWS)		4	9	16	19	22	24	26	27	29	31			
CALCULATED INDOOR Lp PER ISO 9613.2 @	**750M**	**54**	**48**	**42**	**31**	**26**	**20**	**13**	**4**	**-22**	**-100**	**23.2**	**49.5**	**26.3**

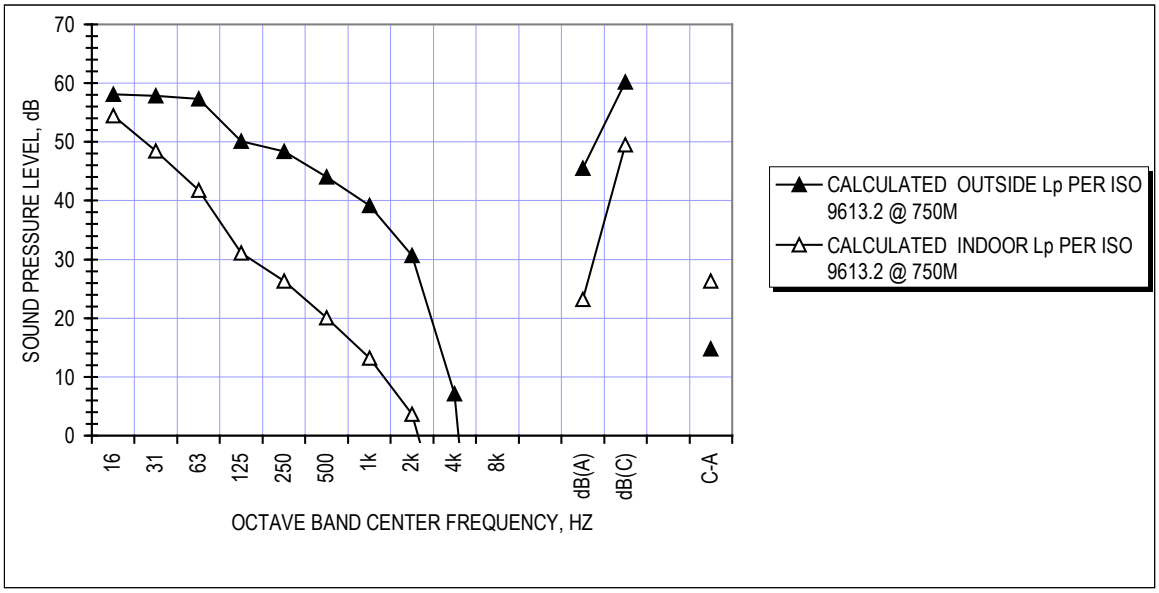


Figure 6

Note the interior spectrum is based on a Noise Reduction (NR) developed as follows.

Figure 7 below plots the NR measured in an early study[3] for aircraft and traffic sources. The black filled and open circles plot the measured NR in the audible frequency range from the 63 to 8000 Hz octave bands. While this study is over 40 years old, its value is the data base of 116 measurement sites. It can be reasoned that energy saving building design today provide higher noise reduction and hence the NR values are almost certainly conservative.

The red dashed line plots the mass law transmission loss (TL) for a relatively lightweight non-masonry building wall and windows. While meaningful above 63 Hz, there is of course no theoretical reason that mass law TL should apply to NR for frequency bands below 63 Hz.

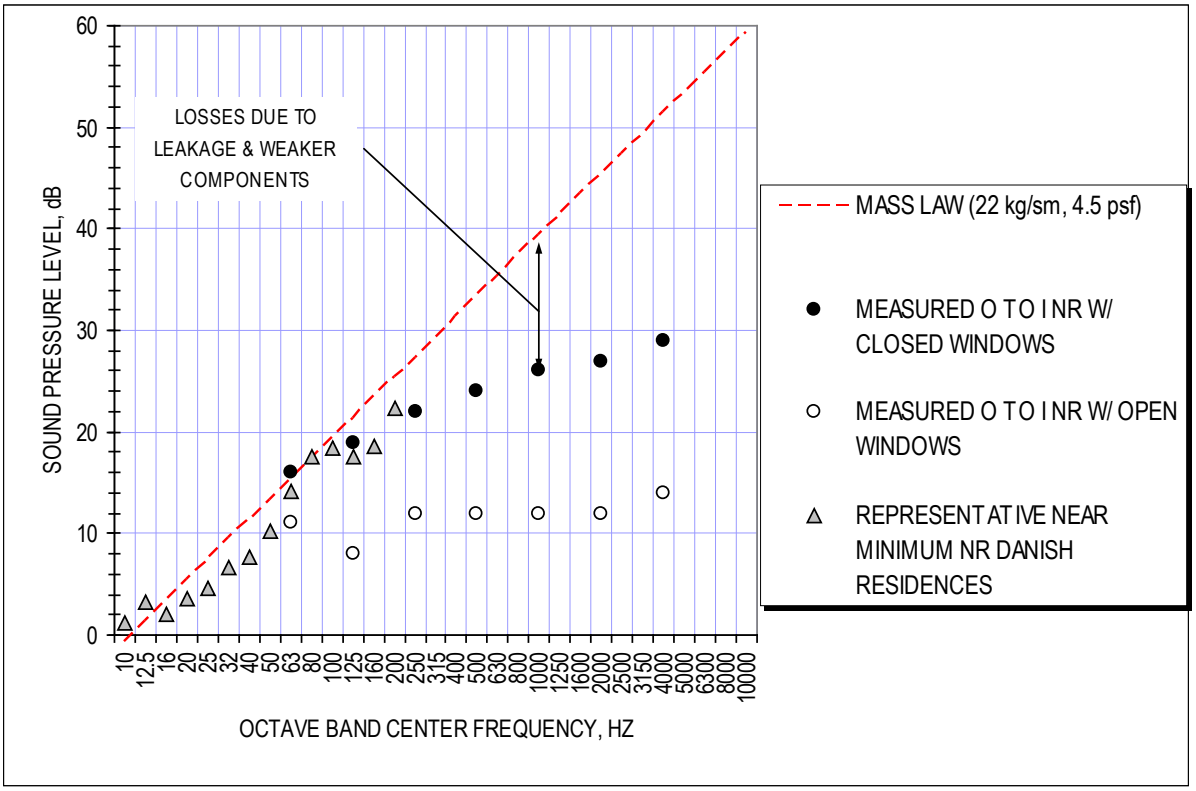


Figure 7

The grey colour triangle markings plot the best *conservative* estimate for low frequency NR of Danish dwellings based on recent a study [4] in 2010. For convenience and conservatism, the NR used in Figure 6 is the calculated mass law TL in the 16 and 31 octave bands and the cited measurements of NR for 63 Hz and above.

Evaluation of Developed Pressure Spectra with Annoyance Thresholds

We have now a representative spectrum for both outdoor and indoor spaces at residences near modern wind projects. The first thing we can look at is the threshold of perception for LFN. This is shown graphically on **Figure 8** below. The range of perception thresholds at low frequencies is discussed and summarized nicely in reference [5] and is shown as the range for current research. We can immediately conclude from this data that infrasound (below 20 Hz) is a non-problem since the wind project noise is 20 to 40 dB below the perception threshold.

We can also see that LFN becomes perceptible at approximately 30 and 60 Hz outdoors and indoors, respectively. When perceptible, are the spectra magnitudes annoying? Research in Japan on LFN annoyance thresholds can provide valuable tools.

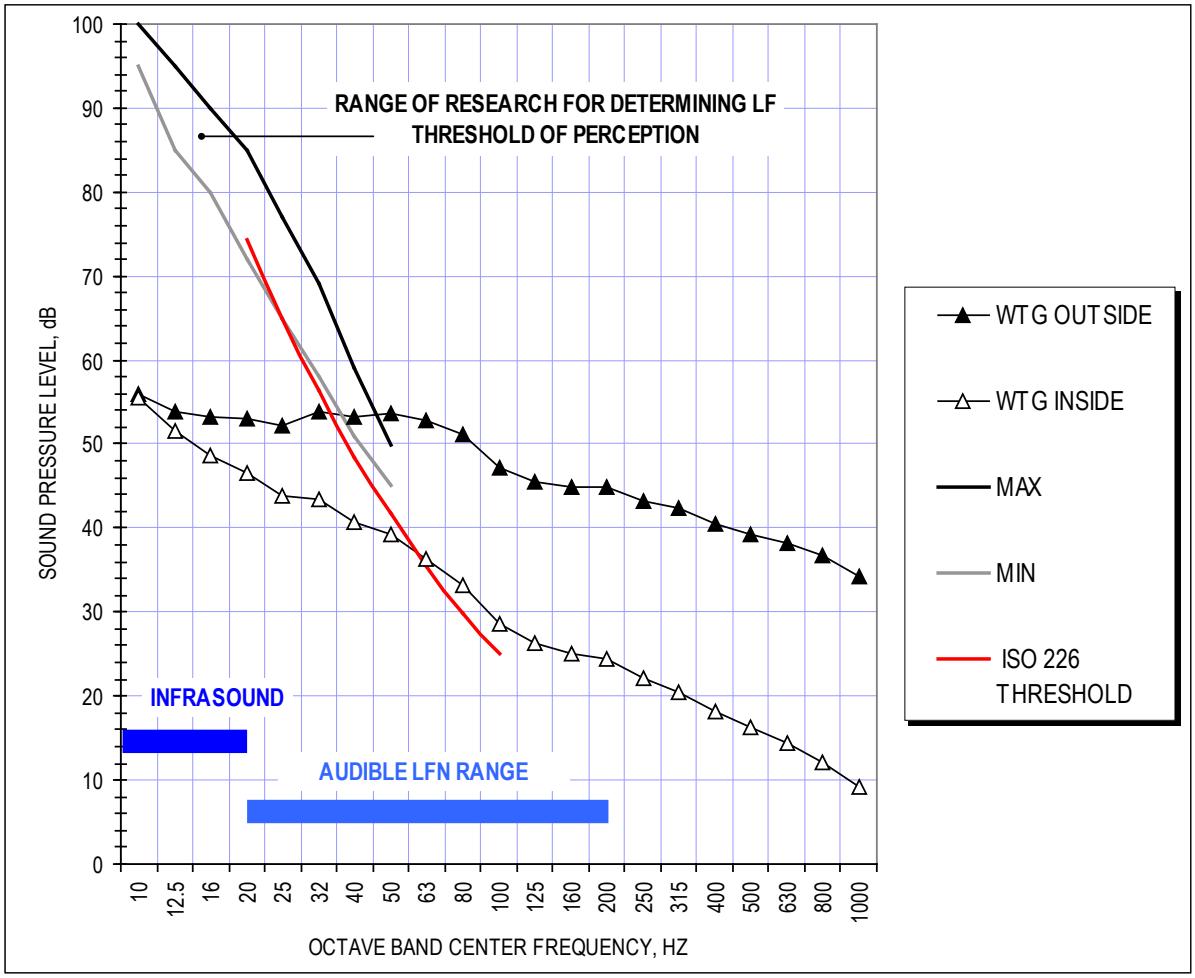


Figure 8

Nakamura and Tokita research[6] using independent test audiences provide the thresholds in **Figure 9** that are plotted with the developed wind project spectra. This work says the outdoor noise spectrum becomes perceptible at 40 Hz, but never exceeds the threshold for potential annoyance. Similarly, Inukai[7] has developed an Unpleasantness Index, again based on test audiences as presented in **Figure 10**. Based on this work, the wind project spectra at the closest residences would be perceived as "Somewhat Unpleasant" and "Not Unpleasant at All" outdoors and indoors. This is based on the normal limit of LFN at 200 Hz.

Some authors and agencies define 'annoyance' as having an adverse effect on health. Even by this definition, one may conclude there are no adverse health effects due to LFN since there is no predictable annoyance.

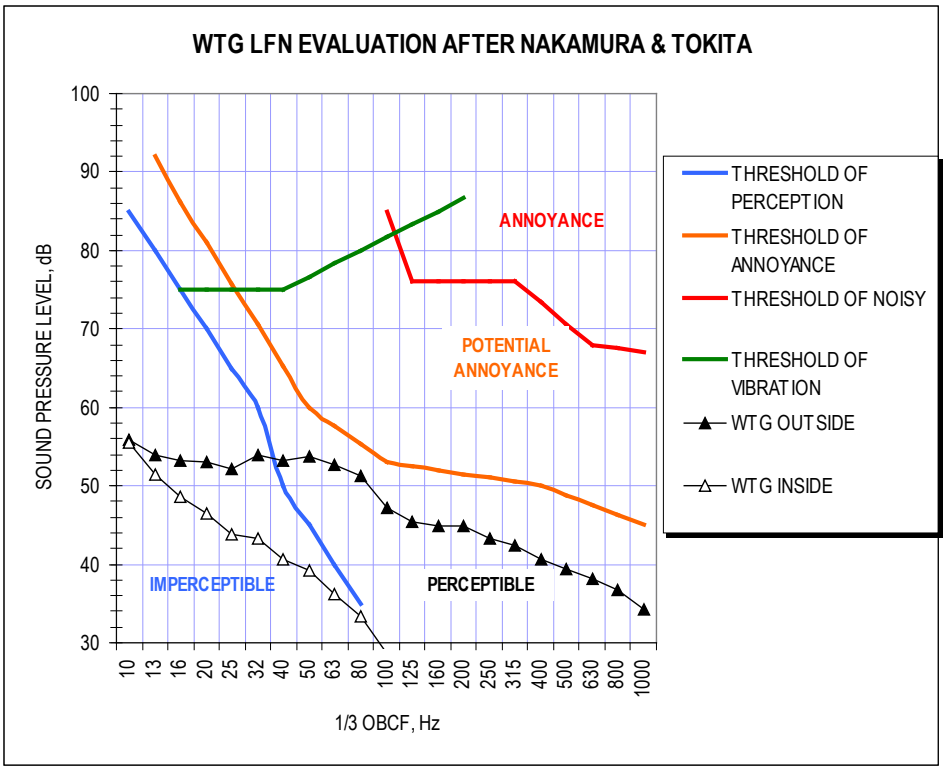


Figure 9

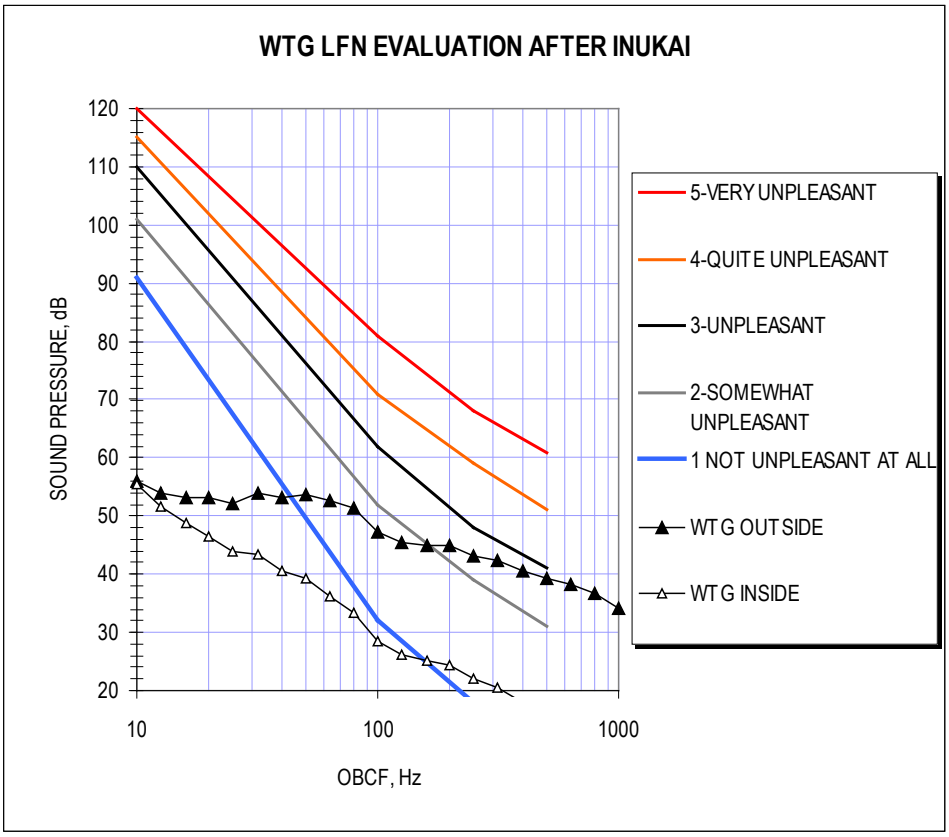


Figure 10

Wind Turbine Project LFN compared to another LFN Source

One way to create infrasound is to simply lower a rear window in an automobile at highway speeds**.** We often compare LFN encountered in practice against annoyance indexes developed in test audiences. **Figure 11** below plots the measured spectra with a rear window open and closed. Note that painful infrasound in the 16 and 31 Hz 1/3 octave bands is created. Of interest here is that the closed window spectra would be judged at levels 3 to 4 or "Unpleasant to Quite Unpleasant" for this case, a modern automobile at highway speed.

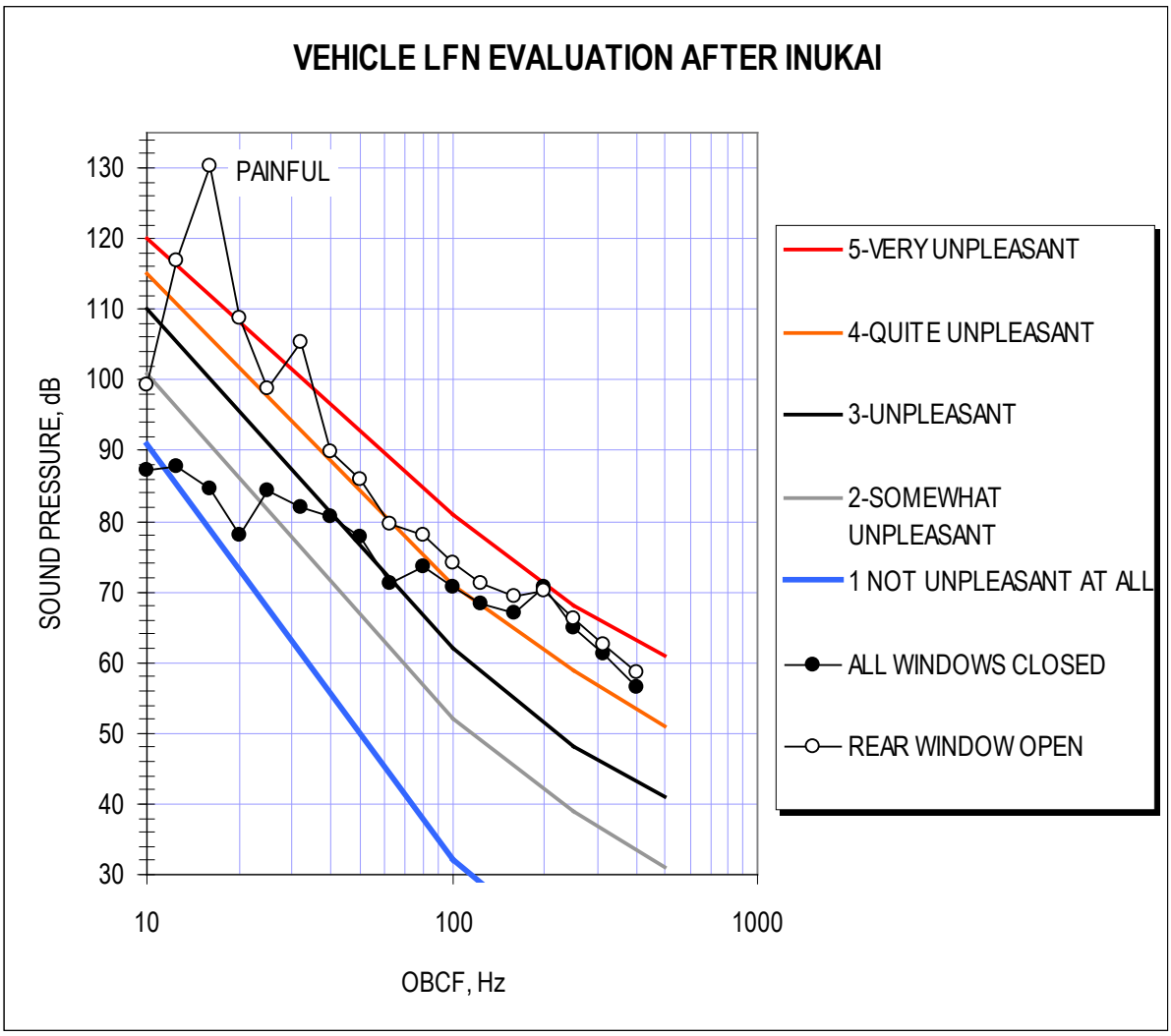


Figure 11

Therefore driving in a modern automobile at highway speed is exposure to LFN. One can safely say there are billions of hours of such exposure to man women and children of all ages throughout the world. To my knowledge, such exposure has never been suspected of causing adverse health effects. It is telling to compare the automobile spectrum with those developed above for wind turbine projects as is done in **Figure 12** below.

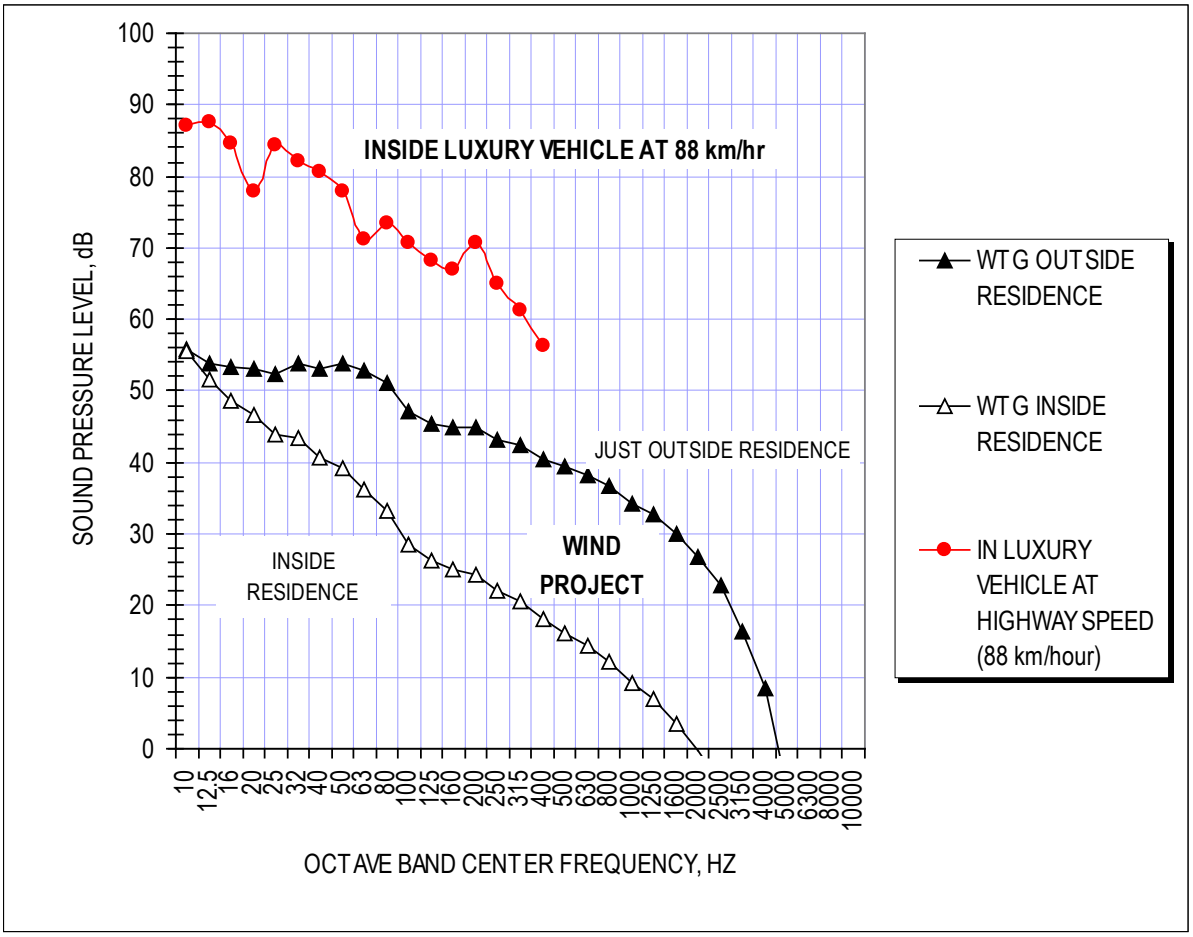


Figure 12

Wind turbine spectra are 20 to 30 dB lower than the level experienced in an automobile at highway speed. It is inconceivable to me that one can reason or even suspect that LFN is an issue at wind projects. Adding to this, we have never received or even heard of noise complaints at any wind farm where complainants reported typical low frequency symptoms.

Conclusions

The indisputable sound power from large wind turbines was developed using independent measurements from 45 wind turbines. Conservative pressure spectra were calculated both outdoors and indoors for the largest possible currently available wind turbine at typical wind project buffer distances. Spectra were compared to scientifically developed LFN annoyance criteria using group response to controlled LFN. In addition, wind turbine spectra were compared to a common source of LFN that has been exposed to men, women and children of all ages for billions of hours with no reported ill effects from noise at any frequency. Common sense brings me to the conclusion that LFN at wind projects is a non-issue and should not be endlessly debated for every proposed wind project.

References

[1] Petersen, C. S., Moller, H., "An analysis of low frequency noise from large wind turbines", 14th International Noise and Vibration and its Control, Figure 2, Aalborg, Denmark, 9-11 June 2010.

[2] Hessler, D. M. & Hessler, G. F., "Recommended noise level design goals and limits at residential receptors for wind turbine developments in the United States", Noise Control Engineering Journal, Number 59(1), Jan-Feb 2011.

[3] Sutherland, L.C., "Indoor Noise Environments Due to Outdoor Noise Sources", Noise Control Engineering Journal, Nov-Dec 1978.

[4] Hoffmeyer, D and Jakobsen, J, "Sound insulation of dwellings at low frequencies", 14th International Meeting on Low Frequency Noise and its Control, Aalborg, Denmark 9-11 June 2010.

[5] Howe, B. and McCabe, N., "LOW FREQUENCY NOISE AND INFRASOUND ASSOCIATED WITH WIND TURBINE GENERATION SYSTEMS, A LITERATURE REVIEW", HGC Engineering report 'DRAFT FOR DISCUSSION', prepared for the Ontario Ministry of the Environment, ref. RFP No. OSS-078696, dated August 3, 2010.

[6] Nakamura, S., Tokita, Y., "Frequency Characteristics of Subjective Response to Low Frequency Sound", Proceedings to Inter-Noise 1981, 1981

[7] Inukai, Y. et al, "Unpleasantness and acceptable limits of low frequency sound", Journal of Low Frequency Noise, Vibration and Active Control, Volume 19, Number 3, September 2000