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"Big Noise Data" for wind turbines

Claus BACKALARZ[1], Lars Sommer SØNDERGAARD[2], Jens Elgaard LAURSEN[3]

[1,2,3] DELTA, Venlighedsvej 4, 2970 Horsholm, Denmark

ABSTRACT

DELTA has in the recent years been involved in two major health projects whose aim was to find possible correlations between noise exposure and health effects. The basis of the investigations in both cases have been "Big Noise Data" in the form of large amounts of historical data for respectively meteorology and road traffic. In 2014-2015, DELTA for The Danish Cancer Society (DCS) made a calculation of all Danish onshore wind turbines noise contributions at the surrounding dwellings for the years 1982-2013. In 2015-2016 DELTA for University of Copenhagen has calculated the contribution of noise from road traffic at 132,000 dwellings over the years 1970-2014. This paper describes the noise calculations of wind turbine noise at 553,066 dwellings situated near wind turbines and the visibility of the wind turbine as seen from these dwelling. Reference is made to The Danish Cancer Society regarding the results of the medical study (1).

Keywords: Wind turbines and wind farms, Sound propagation, Effects of noise on health, Propagation models

1. The Danish Cancer Society study

The study was initiated by the Danish parliament due to protests against the installation of wind turbines from, among others, neighbors with reference to possible pathogenic effects.

1.1 Purpose of the study

The project aims to investigate whether

1. Acute exposure to noise from wind turbines is associated with an increased risk of heart attack and stroke
2. Prolonged exposure to noise from wind turbines is associated with increased risk of cardiovascular disease and diabetes
3. Prolonged exposure to noise from wind turbines is associated with increased use of prescription medications for high blood pressure, sleep problems and depression
4. Exposure to noise from wind turbines during pregnancy is associated with increased risk of low birth weight

1.2 Who is in the test group?

For the acute disease (heart attack and stroke) the Danish National Patient Register, which records all hospital admissions in Denmark, will be used. In the statistical analysis, The Danish Cancer Society for these people compare the level of wind noise on the day(s) leading up to the hospital admission with the blood clot which again is compared with the level of wind noise on a number of similar days (same day of the week and time of year) before their admission.

For long-term effects (cardiovascular disease, diabetes, drug consumption and birth weight) DCS will also use the unique Danish patient registers on these issues.

DCS will calculate continuously the 1-, 5- and 10-year average of exposure to wind turbine noise for each hospitalized person and for the pregnancy period for pregnant women. DCS will also obtain from Statistics Denmark information on socioeconomic status of the test group and a control group for comparison, as well as information about traffic volume at all dwellings in the study to investigate to

[1] cb@delta.dk
[2] lss@delta.dk
[3] jel@delta.dk

what extent any observed relationship can be attributed to variation in these conditions. Besides, the selection of the comparison group (without exposure to wind turbine noise) from the same locality as people who are prone to wind noise result in a higher similarity between noise exposed and non-noise exposed persons. Based on this DCS will perform statistical analysis examining whether the risk of cardiovascular disease, diabetes, increased consumption of medicine (blood pressure, sleep and depression), and low birth weight increases with the degree of exposure to wind noise.

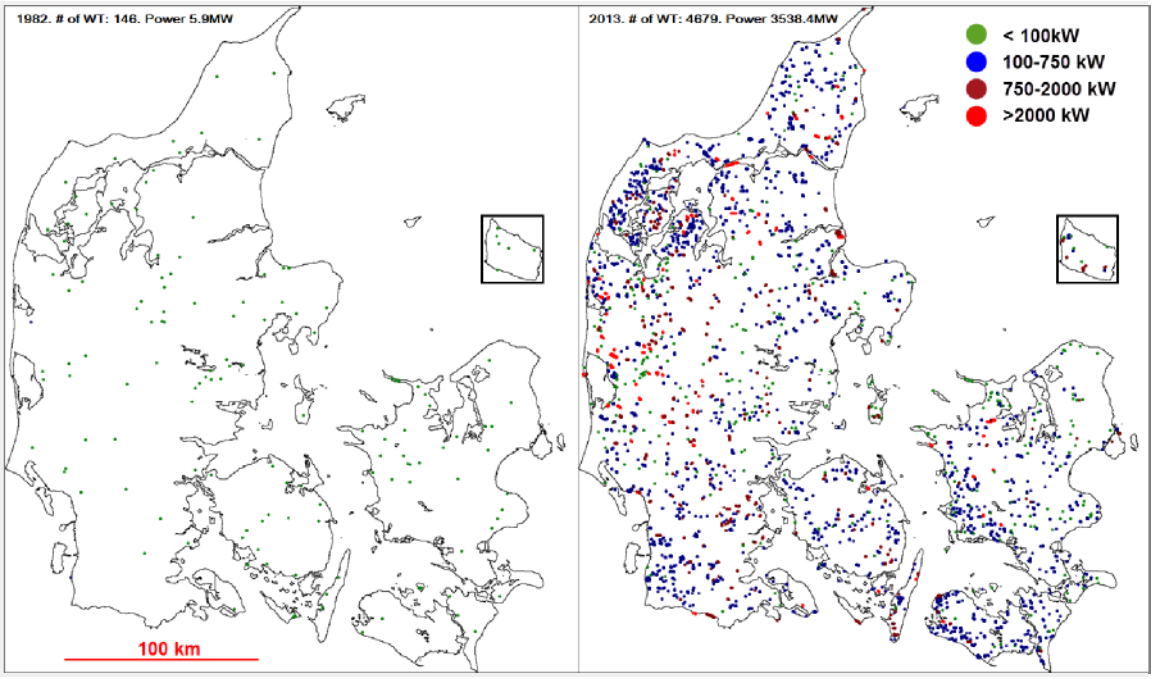

Figure 1 – Onshore wind turbines in Denmark. Left: Wind turbines in 1982. Right: 2013.

2. THE DIVISION OF THE TASK

The subcontractor task is divided into the following subprojects:

2.1 Subproject 0. (DELTA)

Finding exposed dwellings. This is the first rough calculation to define the search radius Rs around each wind turbine/wind farms. Within Rs the dwellings are exposed to either L_{Aeq}>24dB(A) (outdoor) or L_{pALF}>5dB(A) (indoor). 553,066 dwellings met this criterion.

2.2 Subproject 1. (DELTA)

Finding sound power levels L_{WA} for all 7256 wind turbines in the survey between 1982 and 2013 at wind speed 4-25m/s and in the frequency range 10-10.000Hz.

2.3 Subproject 2 (Technical University of Denmark, DTU)

In this project, meteorological data for Denmark is calculated for each of the 280,488 hours in the period 1982-2013 at the 7256 wind turbines locations in Denmark. The meteorological data are to be used in Subproject 3b. This subproject is described in (2).

2.4 Subproject 3a. (DELTA)

Estimate sound insulation for all 553,066 dwellings that were found in subproject 0.

2.5 Subproject 3b. (DELTA)

Calculate noise contributions L_{Aeq} (outdoor) and low frequency noise contributions L_{pALF} (indoor) for 553,066 dwellings and for every hour during the period 1982-2013 (280,488 hours in all).

2.6 Subproject 3c. (DELTA)

Processing the results to find results on daily basis for L_{den}, L_d, L_e, L_n, L_{24h}, L_{denMax} etc.

2.7 Subproject 4. (DELTA task)

Calculate the visibility of all wind turbines within a 5 km radius seen from each of the 553,066 dwellings.

DELTA's part of the study does not include masking effects by noise from vegetation or noise contributions from other noise sources than wind turbines.

3. INPUT DATA FOR THE NOISE CALCULATIONS

A. Danish Energy Agency's register for wind turbines which contains details of all wind turbines installed in Denmark since 1977. The register contains information about locations (UTM32 co-ordinates) commissioning, dismantling, make, type, hub height and rotor diameter. The register contains data for app. 5000 wind turbines in operation, and app. 2500 decommissioned wind turbines. A total of 7256 onshore wind turbines were selected for the study. No offshore turbines are investigated.

B. Measured sound power for many wind turbines. DELTA has made many noise measurements on Danish wind turbines since 1980 that are included in Subproject 1. Similarly, The Danish Environmental Agency, EPA, has published a catalog of the sound power of older wind turbines. Interviews with wind turbine manufacturers are also included.

C. Addresses from the Danish Building and Housing Register with information on the dwellings nature (brick, aerated concrete, lightweight facade etc.).

D. Meteorological data from Denmark hour by the hour in the period 1982-2013 near each wind turbine in the study.

E. Surface and terrain data for Denmark in 1.6x1.6m^2 and 10x10m^2 squares for the calculation of the visibility of the turbines.

4. NOISE CALCULATIONS – THE METHOD

To calculate the noise contributed at the dwellings the Nord2000 method is selected. Nord2000 was developed in the years 1996-2001 as a Nordic collaboration involving DELTA (Denmark), SP (Sweden) and SINTEF (Norway) (3). The method is an accurate noise propagation calculation tool that is unique because it can include the actual weather conditions. Nord2000 has been tested and validated for wind turbine noise calculations (9). Normally noise propagation methods use general simplified meteorological assumptions, e.g. constant down wind and temperature inversion. The advantage of including the influence of the current meteorological conditions makes the method very suitable when (for reasons of study of acute health effects) the noise contribution is to be calculated on a daily and even hourly basis. Basically the method computes the noise levels in 1/3 octave bands from 25 to 10,000 Hz. The method has for this study been modified so that the 1/3 octave bands 10, 12, 16 and 20 Hz are also calculated. The disadvantage of Nord2000 is the long calculation times compared to other more simple methods like ISO 9613-2.

5. CALCULATION OF Rs AND SELECTION OF DWELLINGS

Initially dwellings with a sufficiently high noise exposure were to be selected. Since it was desirable to quickly single out the exposed dwellings calculations of the noise exposure was made with the simple and fast method described in the Danish wind turbine Statutory Order (4), which regulates the establishment of wind turbines. This method is based in part on the Nord2000-method but meteorological parameters are simplified, so there is always calculated worst case i.e. downwind in all directions and temperature inversion.

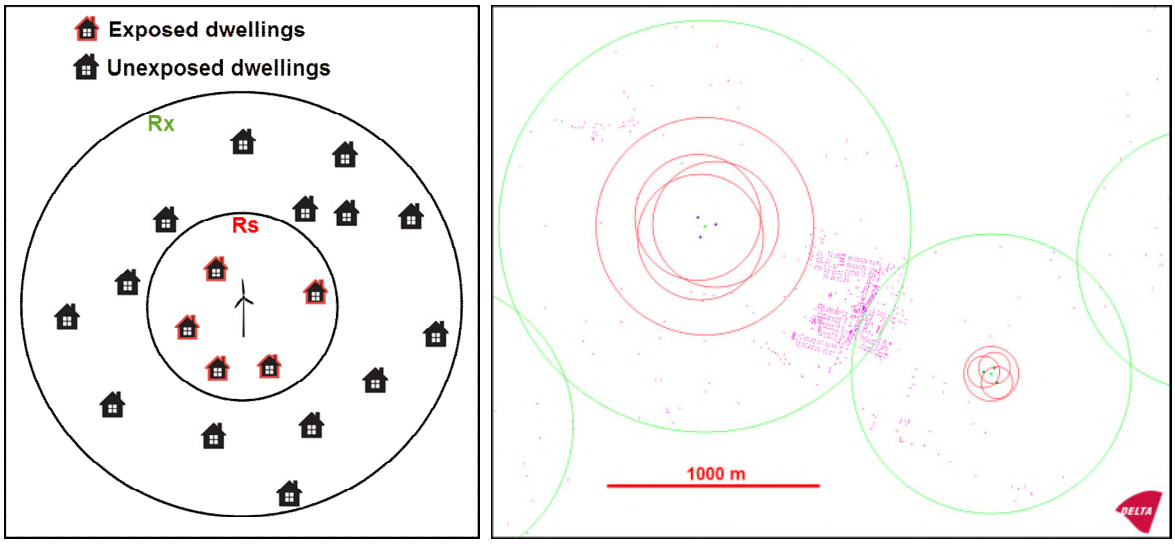

Figure 2 – Left: Illustration of radius Rs. Right: Calculated Rs, green for L_{pA}, red for L_{pALF}.

Because of the few parameters (distance, hub height, ground, air absorption, flat terrain), the calculations are quick to make. Since the sound power levels for the approximately 7300 wind turbines on this stage had not yet been found the EPA's catalog data for older wind turbines (6) was used. For wind turbines with rated sound power levels of more than 2 MW average data from some of DELTA's measurements was used.

For the calculation of the indoor low frequency level (L_{pALF}) the standard values for noise insulation in (4) was used. By using these it is estimated that 66.6 % of the houses has an equal or better sound insulation than used.

The criteria to decide if a dwelling was exposed to wind turbine noise (and thus should be included in the study) was that the outdoor sound pressure level should exceed 24dB(A) at wind speed of 8m/s at 10m height or the indoor noise L_{pALF} should exceed 5dB(A). In comparison, the Danish limit for L_{pA} and L_{pALF} at the country side are respectively 44dB(A) and 20dB(A) at wind speed of 8m/s.

The Cancer Society asked for a calculated radius Rs around each wind turbine or groups of wind turbines. Within the circle of radius Rs residents were defined as exposed whereas at greater distances than Rs residents were defined as not exposed. The latter can thus be used as a control group.

Initially, wind turbines in parks were grouped within a radius of 1 km from the center of the group of wind turbines. In this way 1,529 groups were found containing a total of 6,078 wind turbines. Furthermore 1,178 single wind turbines (not part of a windfarm) were found. The largest group contained 100 turbines and there were groups down to 2 wind turbines.

Then Rs was calculated for the groups and for single wind turbines corresponding to L_{pA}=24dB(A) or L_{pALF}=5dB(A) in the distance Rs. For groups, calculations were made with the group's total sound power with the equivalent sound source located geographically in the middle of the group and at a height corresponding to the highest wind turbine in the group.

The largest radius Rs of 6,500 m was found for a group of 18 turbines with a total sound power of 120 dB(A). For all Rs it was noted that L_{pA} - and not L_{pALF} - were the decisive parameter.

On the basis of the total of 2,707 Rs-values The Cancer Society could choose 862,189 dwellings that met L_{pA}>24dB(A) condition.

Later on, after the L_{WA} had been estimated for the individual wind turbines in Subproject 1, new calculations were made, still with the simple method in (4). These calculations resulted in the finding of 553,066 dwellings that met the L_{pA}>24dB(A) criteria. These dwellings were finally selected as the test group of exposed dwellings for the study.

6. ASSESSMENT OF SOUND POWER FOR THE WIND TURBINES

In the Danish wind turbine statutory order from 2011 (4) you are required to calculate the noise contribution from all wind turbines in the surroundings that could potentially contribute to the noise at the neighbors. That means that sound power data for both the older wind turbines in the area and the new projected turbines should be known. With the statutory order (4) you were also required to

calculate the indoor low frequency noise contribution L_{pALF} (10-160 Hz) and there was therefore a need to know the sound power effect down to 10 Hz for existing and future wind turbines.

Hence came the need to know the sound power levels for older wind turbines, and the Danish EPA published a report with typical noise spectra for 9 classes of wind turbines (5). Furthermore there were published a catalog with the sound power of 89 older wind turbines (6). Thus in the years around 2011-14 there were done a large effort of collecting noise data for older wind turbines erected in Denmark.

In general, the Danish wind turbine statuary orders since 1991 (10) have specified that the sound power level of a wind turbine shall be measured at the wind speed 8m/s at 10m height, and in 2006 the new statuary order (11) also specified measuring at the wind speed 6m/s. This means that most documentation reports of older wind turbines only contains results from one or two wind speeds. This is reflected in (5) and (6).

The EPA-report (5) specifies data of 9 wind turbine classes of corresponding sound power levels in 1/3 octaves with center frequencies in the range 10 to 10,000Hz at wind speed 6 and 8m/s at 10m height. Yet in (6) the sound effects are given in 1/1 octaves with center frequencies in the range 63 to 8000Hz.

The calculations of the noise contributions at the neighbors in the study in principle requires information retrieved for all 7,256 wind turbines containing sound power levels in 1/3 octaves from 10-20,000Hz at all wind speeds in the interval 4-25m/s at 10m height.

Data for each of the many wind turbines does in general not exist, and not for all frequency bands and wind speeds. DELTA's evaluations was therefore based on the sound power levels from (5, 6) as well as reports and data from DELTA's many wind turbine measurements, a substantial amount of these collected and used in (12, 13). In subproject 1, DELTA estimated sound power levels (10-20,000Hz, 4-25m/s) for 99 different types of wind turbines. Then all of the 7256 wind turbines in the survey was assessed and assigned with one of the 99 spectra.

All of the 7,256 wind turbines in the survey was assessed and assigned with one of these 99 spectra. An example is given in Figure 3.

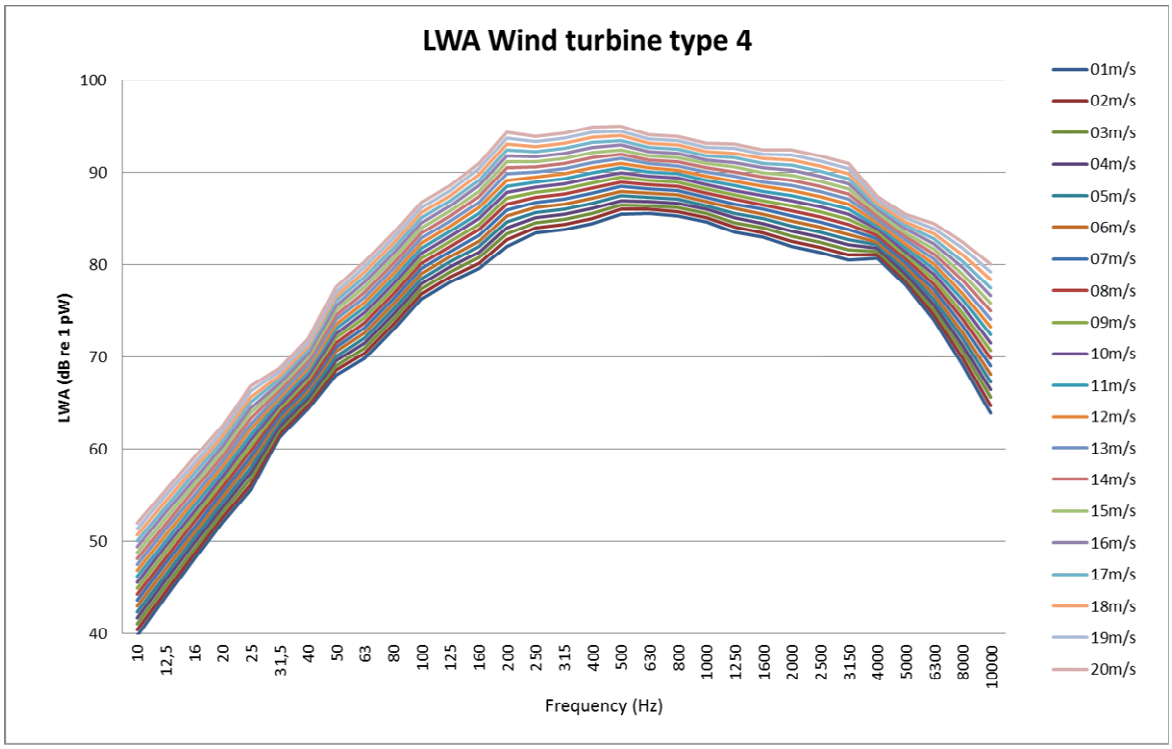

Figure 3 – An example of sound power 10-10,000Hz at wind speed 1-20m/s.

In addition to estimating the sound power levels for each of the 99 wind turbine classes, it was assessed whether the turbines could produce noise that potentially contained clearly audible tones. This was indicated by the indicators -1, 0, 1 and 2:

-1: No knowledge whether this turbine class has audible tones, 0: No clearly audible tones at a distance equal to the total height of the wind turbine is found for this wind turbine class, 1: There are cases with clearly audible tones at a distance equal to the total height, but no cases are known of clearly audible tones at neighbor distance and 2: There are cases of clearly audible tones at neighbor distance.

Finally, for each of the 99 wind turbine classes a standard deviation was calculated for each 1/3 octave band and for each wind speed depending, among other things, of the number of wind turbines that were included in the data for each wind turbine class.

The many assumptions and considerations for the assessment of wind turbine sound power are described in (7). Figure 3 shows an example of the sound effect for one of the 99 wind classes (Type 4).

7. ASSESSMENT OF SOUND INSULATION FOR DANISH HOUSES

DELTA has in 1997 and 2006 measured sound insulations in typical Danish houses, i.e. the spectral difference between outdoor and indoor noise level. The measurements are described in (8). In total there are measured 14 houses and 26 rooms. These measurements are used to estimate sound insulation in the frequency range 10-160 Hz, which is required if you want to calculate the internal low frequency noise on the basis of the external sound pressure.

By combining the measurement results from the surveys in 1997 and 2006, the Danish houses were divided into 5 groups in subproject 3a: Brick, porous concrete, farmhouse, light facade (e.g. wood) and light roof (e.g. steel plate, roofing felt). The level difference for these house types are shown in Figure 4.

Based on data from the Danish Building and Housing Register, for most of the 553,066 dwellings that were included in the study, the sound insulation could be applied to each house in the frequency range 10-160 Hz. For some houses data was missing from the Building and Housing Register so that the building type could not be identified. In these cases the average of the insulation values for the 5 groups was used.

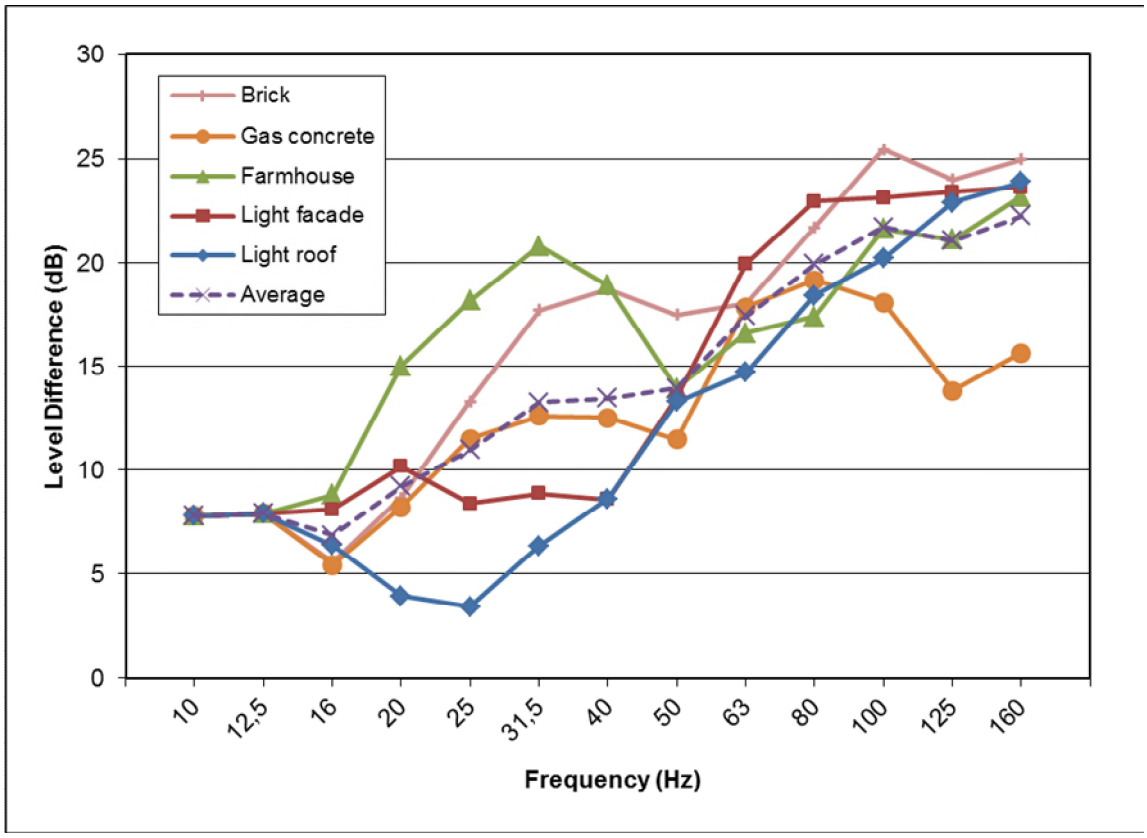

Figure 4 – Level differences for typical Danish houses

8. METEOROLOGY DATA

For the sake of examination of the acute health effects meteorology data is needed hour by hour for the period 1982-2013.

The Nord2000-method needs, in the modified version that is used in this study, 5 parameters for each hour: the wind speed and wind direction at hub height, temperature and relative humidity in the height of two meters and the coefficient 1/L. The parameter L is the Monin-Obukhov length and 1/L is descriptive of the atmospheric stability. If 1/L is negative the atmosphere is unstable, 0 means that the atmosphere is neutral. If 1/L is positive the atmosphere is stable, corresponding to temperature inversion.

On the basis of the 5 parameters Nord2000 can calculate the effective speed of sound as a function of height above ground level which - together with the source height, receiver height and terrain absorption - is the most important input parameter for Nord2000 for wind turbine calculations.

These 5 parameters are found by The Technical University of Denmark for the approximately 7,300 wind turbines hour by hour in the years that the wind turbine has been in operation.

An example of the meteorological data for a wind turbine is shown in Figure 5.

Time stamp	Windspeed hub	Direction hub	Temp 2m (°K)	RH 2m	1/L
199607110000	7.060070	287.064392	287.574890	83.036110	0.000024
199607110100	6.288479	287.338013	287.541687	84.918434	0.000164
199607110200	6.166970	285.553284	287.674103	85.557106	0.000206
199607110300	6.411914	284.841248	287.653107	86.457108	0.000173
199607110400	7.256513	285.249268	287.534393	86.907318	0.000079
199607110500	6.952989	283.054779	287.795807	84.966080	-0.000068
199607110600	6.541962	289.637177	288.226135	83.245697	-0.000625
199607110700	6.146949	283.507751	288.492493	82.253357	-0.000880
199607110800	5.814772	268.968872	289.312256	79.617989	-0.001711
199607110900	5.830414	264.440887	289.337952	79.117546	-0.001186
199607111000	5.803030	276.304810	290.401306	75.236076	-0.001200
199607111100	5.787663	279.668274	290.765198	74.555061	-0.001567
199607111200	5.642738	280.204834	291.023438	73.926651	-0.001882

Figure 5 – Examples of meteorology data from The Technical University of Denmark

9. NOISE CALCULATIONS

There are no commercial noise calculations programs that rationally can handle Nord2000 calculations in the scale this study requires. Furthermore the meteorological parameters that could be provided for the study period 1982-2013 do not fit commercial programs.

The total number of operating days for the 7256 wind turbines is 41,707,639. There should therefore be carried out investigations for 553,066 dwellings x 41,707,639 days x 24 hours = 553,609,849,708,176 noise transmission paths. For dwellings inside Rs there were carried out real Nord2000 calculations.

With this in mind DELTA has expanded our PC-based calculation program for wind turbines WTTool to be able to handle the calculations for this study. The calculations were carried out on 7 fast PC's each with 8 CPU cores.

Because wind turbines are high and the dwellings therefore usually have "acoustic free sight" to the turbines (which means that there are no solid objects which can screen the noise propagation) there are not included screening objects such as houses in the calculations. In addition, the terrain is everywhere assumed acoustically porous since the wind turbines in most cases are placed at the countryside.

The calculations consist mainly of the following steps:

A. Housing and wind turbines are divided into 86 municipalities. There are 98 municipalities in Denmark in which 86 contain wind turbines. For municipalities with many wind turbines the dwellings are divided in groups of 1,000-5,000 houses so calculations continuously can be distributed equally between the 56 CPU cores.

B. For each dwelling the area within a radius of 6 km are searched for wind turbines. For each identified turbine there is made a rough calculation using the simple EPA method in (4). If the noise

contribution is greater than L_{Aeq}=20dB(A) Nord2000 calculations are performed hour by hour in the years where the wind turbine is in operation. Otherwise the wind turbines small contributions are omitted. For each selected turbines both L_{pA} (outdoor) and L_{pALF} (indoor) are calculated. L_{pALF} is calculated on the basis of the sound insulations values from subproject 3a. For each dwelling the noise from all contributing wind turbine are summarized for each hour in 1982-2013.

C. When the noise contributions from all turbines have been summed up for a dwelling the following parameters are calculated for each 24 hour period: L_d, L_e, L_n, L_{24h} (mean value over 24 hours), L_{dLF}, L_{eLF}, L_{nLF}, L_{24hLF}, L_{dMin} (minimum hourly value for L_d 07-18), L_{dMax} (largest hour value for L_d 07-18), L_{eMin}, L_{eMax}, L_{nMin}, L_{nMax}, L_{24hMin}, L_{24hMax}, L_{dLFMin}, L_{dLFMax}, L_{eLFMin}, L_{eLFMax}, LnLFMin, L_{nLFMax}, $L_{24hLFMin}$ and $L_{24hLHMax}$. This is a total of 24 results per day. Furthermore, it is calculated how many hours a day that the dwelling received noise contribution from wind turbines with tone index -1 (unknown), 0 (no tones), 1 (toner near the turbine) and 2 (possibly audible tones from the turbine at the dwelling). Finally the validity of the results is calculated. Small validity numbers mean little uncertainty on the result, large numbers mean greater uncertainty. The validity is indicated by dL_d, dL_e, dLn, dL_{24h}, dL_{dLF}, dL_{eLF}, dL_{nLF} and dL_{24hLF}.

The tone index is reported in the output file as 4 columns. No tone (or impulse) penalty is added to the results.

The calculations of the noise contributions for all 553,066 dwellings hour by hour through 32 years took about 100 hours. Several additional runs were performed due to errors found by quality control both at DELTA and DCS.

An example of the results over 10 days in 2002 are listed in Figure 6 for a dwelling near many wind turbines which is illustrated in Figure 7. The results in the form of L_{24h} (A-weighted mean for the day period) and L_{24hLF} is shown as graphs in Figure 8.

The results were delivered to The Cancer Society in May 2015 in the form of 553,066 tab-delimited files, each containing results for one dwelling in the period 1982-2013. A total of 705 GB data.

Time stamp	Ld	Le	Ln	L24h	LdLF	LeLF	LnLF	L24hLF
20020124	35,5	35,3	35,1	35,3	5,4	6,1	5,7	5,6
20020125	35,1	32,2	36,4	35,3	5,1	2,6	6,2	5,2
20020126	37,7	37,9	37,4	37,6	7,0	7,2	6,7	6,9
20020127	30,8	32,8	37,2	34,5	1,8	2,6	6,6	4,3
20020128	39,9	42,9	39,6	40,5	9,4	12,6	9,4	10,1
20020129	35,2	37,7	37,4	36,6	4,8	7,1	6,7	6,0
20020130	35,8	37,1	35,9	36,1	5,2	6,5	5,2	5,4
20020131	36,2	34,6	37,6	36,6	5,6	4,1	7,0	6,0
20020201	37,7	40,3	39,2	38,8	7,1	9,8	8,7	8,3
20020202	38,0	37,5	35,0	37,0	7,6	7,1	4,7	6,6

Time stamp	LdMin	LdMax	LeMin	LeMax	LnMin	LnMax	L24hMin	L24hMax	LdLFMin	LdLFMax	LeLFMin	LeLFMax	LnLFMin	LnLFMax	L24hLFMin	L24hLFMax
20020124	32,3	36,7	34,6	36,0	33,7	36,0	32,3	36,7	4,2	6,0	5,0	6,9	4,9	6,6	4,2	6,9
20020125	29,9	37,7	33,3	33,7	33,7	38,6	29,9	38,6	0,0	7,6	3,6	4,0	4,3	7,8	0,0	7,8
20020126	36,5	38,6	37,7	38,3	35,4	38,2	35,4	38,6	5,8	7,8	7,0	7,6	4,8	7,6	4,8	7,8
20020127	30,4	35,8	33,9	34,3	35,1	38,9	30,4	38,9	3,6	5,5	3,8	4,0	4,6	8,2	3,6	8,2
20020128	37,7	42,1	42,1	43,1	38,1	41,5	37,7	43,1	7,0	11,9	11,9	12,8	7,8	11,2	7,0	12,8
20020129	33,5	37,6	36,6	38,8	34,9	38,8	33,5	38,8	3,2	7,2	5,9	8,2	4,3	8,2	3,2	8,2
20020130	34,5	37,1	37,0	37,2	35,5	36,7	34,5	37,2	4,2	6,4	6,3	6,6	4,7	5,9	4,2	6,6
20020131	33,8	37,6	34,4	34,8	36,3	38,3	33,8	38,3	3,6	7,0	4,0	4,2	5,8	7,7	3,6	7,7
20020201	35,9	39,8	40,3	40,3	38,6	39,7	35,9	40,3	5,3	9,2	9,8	9,8	8,1	9,2	5,3	9,8
20020202	37,3	38,9	37,3	37,9	33,7	36,8	33,7	38,9	6,9	8,6	7,0	7,5	3,6	6,4	3,6	8,6

Time stamp	Tone-1	Tone0	Tone1	Tone2		dLd	dLe	dLn	dL24h	dLdLF	dLeLF	dLnLF	dL24hLF
20020124	720	24	0	0		3,2	9,4	4,2	2,7	32,9	56,1	36,4	22,5
20020125	646	22	0	0		6,5	10,6	10,6	5,9	36,8	64,4	39,3	25,2
20020126	720	24	0	0		8,7	13,8	8,1	5,6	34,6	56,6	37,7	23,3
20020127	540	18	0	0		5,7	11,8	11,7	8,3	45,5	64,4	40,5	29,1
20020128	720	24	0	0		22,8	51,4	22,3	18,8	45,4	83,0	46,6	33,6
20020129	716	23	0	0		6,4	15,5	10,6	6,2	35,3	58,2	39,6	24,6
20020130	720	24	0	0		4,5	8,8	2,8	2,9	33,7	54,9	36,0	22,6
20020131	720	24	0	0		4,7	8,3	9,1	4,8	33,6	55,1	38,0	23,6
20020201	720	24	0	0		13,7	33,7	17,6	11,7	38,3	67,8	42,2	27,2
20020202	720	24	0	0		11,1	14,2	6,0	7,1	35,8	57,0	38,0	24,8

Figure 6 – Examples of results for one dwelling (2002271:0) in ten days

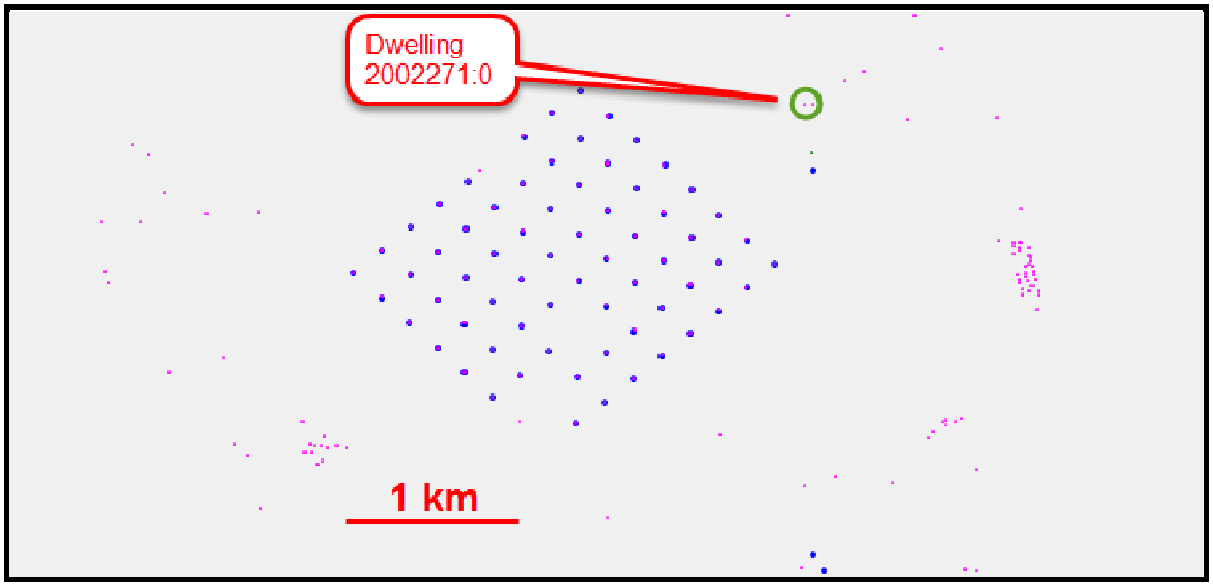

Figure 7 – Dwelling 2002271:0 east of a major windfarm

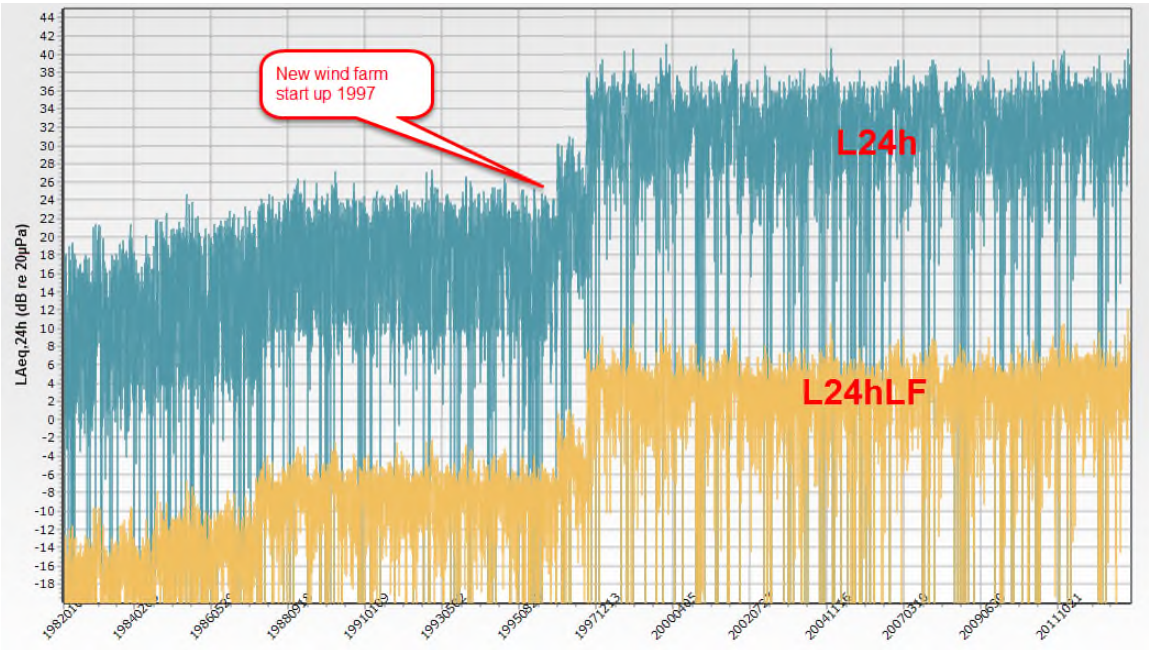

Figure 8 – Some of the results for dwelling 2002271:0. Daily values $L_{Aeq,24h}$ 1982-2013.

10. CALCULATION OF THE WIND TURBINES' VISIBILITY

The visibility of wind turbines may be an important moderator for any inconvenience of living near wind turbines. Therefore, the visibility of the wind turbines was also calculated.

The visibility of the turbines is calculated on the basis of topographic data (terrain heights) for Denmark in 10mx10m squares and surface heights (height of e.g. rooftops, forests and embankments), the latter in grids of 1.6mx1.6m.

The calculations are made for each dwelling and the result is the visibility (in terms of the angle of the free visible part of the wind) of all turbines within 5 km. There are counted for 3 lines of sight per wind turbine: one for total height (hub height + ½ x rotor diameter), one for the hub height offset ½ x rotor diameter to the left and one to the hub height offset ½ x rotor diameter to the right of the wind turbine tower, see Figure 9. For all three lines of sight the angle between the horizontal plan and the

line of sight is indicated. For the left and right focal points only the largest are reported, se Figure 10.

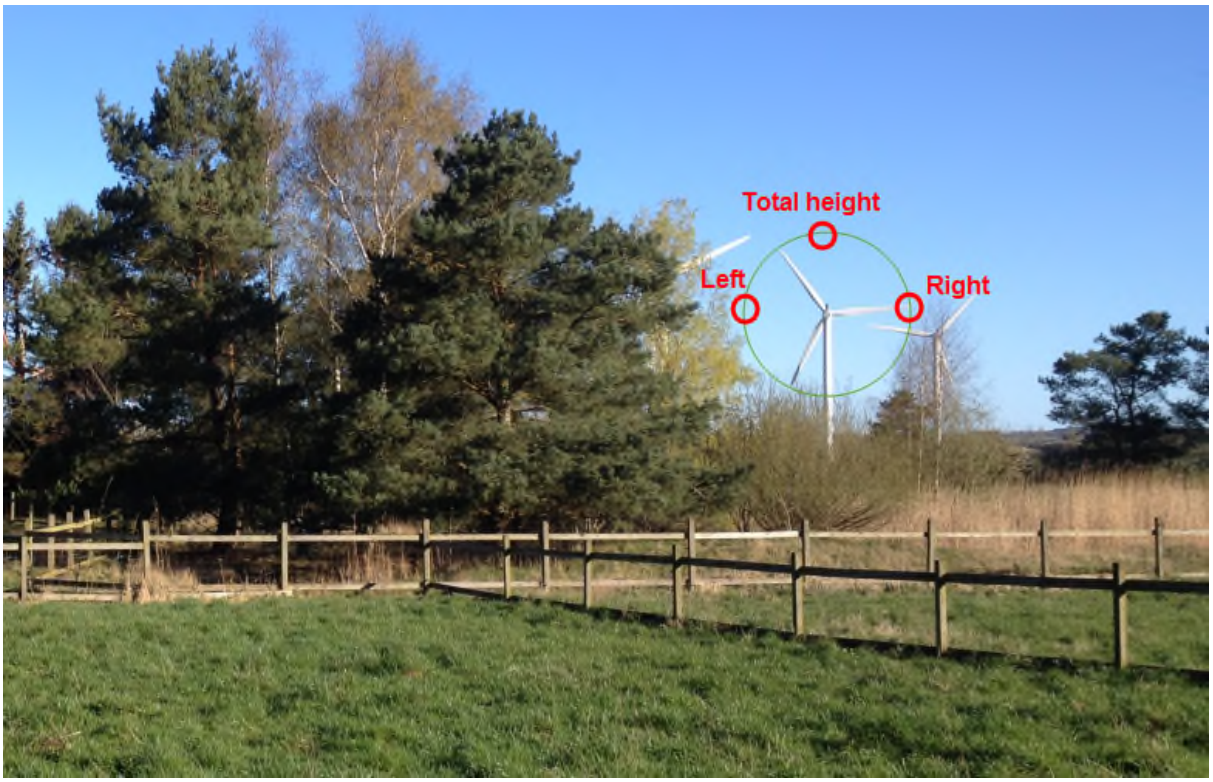

Figure 9 – Visibility of wind turbines. Focal points when calculate angels of free sights lines.

2002271:0											
	Free angel	To Hub	To Total	Distance	WTid	WTStart	WTStop	RotorD	HubH	WTXutm	WTYutm
	(°)	(°)	(°)	(m)							
19-03-1980	02-10-1984										
	1,398	1,098	1,577	1497	5707150000000039000	19-03-1980	14-03-2003	25	29	461837	6208714
03-10-1984	30-04-1985										
	1,398	1,098	1,577	1497	5707150000000039000	19-03-1980	14-03-2003	25	29	461837	6208714
	0,973	0,861	1,210	1558	5707150000000039000	03-10-1984	08-06-2006	19	23	461789	6208760
01-05-1985	14-05-1985										
	1,398	1,098	1,577	1497	5707150000000039000	19-03-1980	14-03-2003	25	29	461837	6208714
	0,973	0,861	1,210	1558	5707150000000039000	03-10-1984	08-06-2006	19	23	461789	6208760
	0,311	0,303	0,410	4277	5707150000000040000	01-05-1985	30-09-2002	16	23	464757	6203758
15-05-1985	08-09-1986										
	1,398	1,098	1,577	1497	5707150000000039000	19-03-1980	14-03-2003	25	29	461837	6208714
	0,973	0,861	1,210	1558	5707150000000039000	03-10-1984	08-06-2006	19	23	461789	6208760
	0,311	0,303	0,410	4277	5707150000000040000	01-05-1985	30-09-2002	16	23	464757	6203758
	0,398	0,293	0,401	4504	5707150000000040000	15-05-1985	28-01-2010	17	23	457937	6207927
	0,387	0,283	0,387	4662	5707150000000040000	15-05-1985	28-01-2010	17	23	457781	6207950
	0,379	0,281	0,385	4693	5707150000000040000	15-05-1985	28-01-2010	17	23	457764	6208048
	0,282	0,279	0,382	4727	5707150000000040000	15-05-1985	28-01-2010	17	23	457746	6208146
	0,375	0,274	0,375	4815	5707150000000040000	15-05-1985	28-01-2010	17	23	457629	6207970
09-09-1986	06-10-1987										
	1,398	1,098	1,577	1497	5707150000000039000	19-03-1980	14-03-2003	25	29	461837	6208714
	0,973	0,861	1,210	1558	5707150000000039000	03-10-1984	08-06-2006	19	23	461789	6208760
	0,311	0,303	0,410	4277	5707150000000040000	01-05-1985	30-09-2002	16	23	464757	6203758

Figure 10 – Visibility of wind turbines. Part of the results for dwelling 2002271:0.

11. SUMMARY

DELTA has calculated noise contribution of all wind turbines in Denmark hour by hour through the years 1982-2013, a total of 32 years with the highly accurate Nord2000-method. The calculation results are to be used by for The Cancer Society's study of possible links between exposure to wind turbine noise and a number of diseases. Especially for wind turbines the meteorology is important for determining the noise impact since both sound power and sound propagation is affected by the meteorology.

The calculations are unique because it – based on detailed meteorological data for 1982-2013 combined with the Danish Registers – has been possible to calculate noise impacts in such detail and accuracy that both short and long-term health effects can be derived.

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