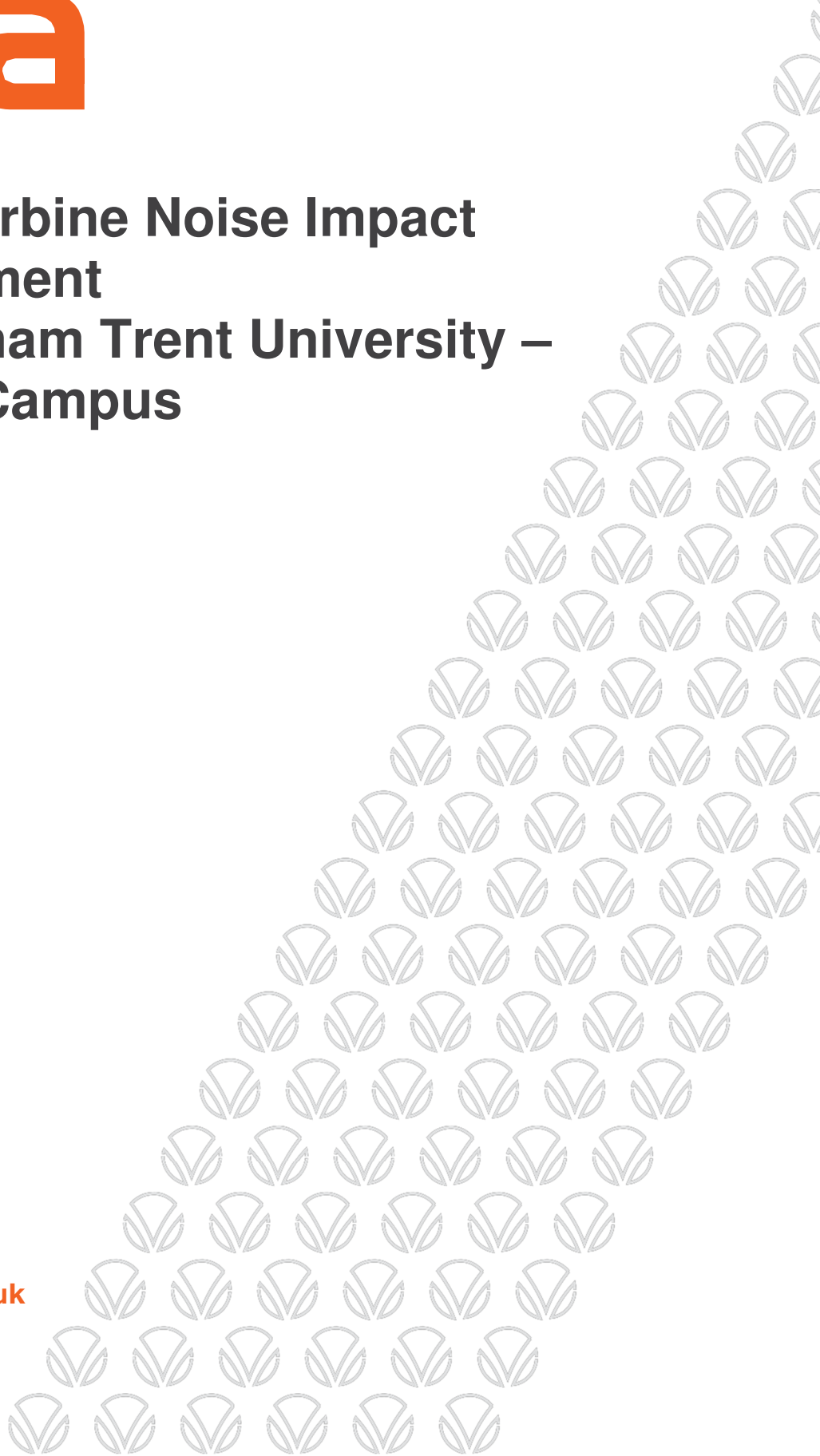




Wind Turbine Noise Impact Assessment Nottingham Trent University – Clifton Campus

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QUALIFICATIONS AND LIMITATIONS

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The following notes should be read in conjunction with the report:

The report has been prepared and written solely for the purpose of providing information regarding the noise impact of a proposed new wind turbine installation at the Nottingham Trent University Clifton Campus in Nottingham. Furthermore, new information, changed practices or new legislation may necessitate revised interpretation of the report after the date of its submission.

Unless specifically referred to, the report has not addressed health and safety matters relating to noise, or liabilities relating to nuisance.

All information, comments and opinions given in the report are based on the information given or obtained.

Via East Midlands Ltd, Environmental Management and Design team, prepared this report for the sole and exclusive use of Nottingham Trent University, in response to specific instructions. Other parties using the information contained in this report do so at their own risk and any duty of care to those parties is excluded.

Contents

1.	Introduction.....	1
2.	Noise Policy Guidance and Consultation	2
2.1	Noise Policy Statement for England (NPSE) ^[1]	2
2.2	ETSU-R-97 – The Assessment & Rating of Noise from Windfarms ^[2]	2
2.3	Professional Practice Guidance on Planning & Noise (ProPG) ^[3]	3
2.4	WHO: Environmental Noise Guidelines for Europe (2018) ^[4]	4
2.5	Consultation	4
3.	Description of the sites	5
3.1	Application Site - Option A	5
3.2	Application Site – Option B	6
4.	Baseline Conditions	7
4.1	Weather Conditions	8
4.2	Background conditions - Site A.....	8
4.3	Background conditions - Site B.....	10
4.4	Short duration attended noise surveys at other NSR locations	11
4.5	Wind Turbine Acoustics Characteristics	13
5.	Assessment Methodology.....	15
5.1	Data Analysis & Filtering.....	15
5.2	Defining the Relationship between Background Noise and Mean Wind Speed.....	15
5.3	Comparison of BNL derived profile and VAWT Noise Profile.....	20
6.	Conclusions and Recommendations.....	26
6.1	Conclusions	26
6.2	Recommendations	26
	REFERENCES	27
	APPENDICES	28

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1. Introduction

Via East Midlands has been commissioned to assess and evaluate the potential Noise Impact from a single proposed Vertical Axis Wind Turbine (VAWT) to be installed at the Nottingham Trent University – Clifton Campus. Currently there are two separate locations under consideration within the campus and both locations have been assessed in this report.

The following technical noise assessment has been produced to accompany a Planning Application and is based upon environmental background noise measurements and an assessment of the noise effects of the installation of the VAWT at surrounding sensitive receptors by using the noise prediction recommended methodologies of the ETSU-R-97 Guidance for both potential locations.

This noise assessment is necessarily technical in nature; therefore, a glossary of terms is included in Appendix A to assist the reader.

2. Noise Policy Guidance and Consultation

2.1 Noise Policy Statement for England (NPSE) ^[1]

The NPSE sets out the Government's policy on noise and includes the long-term vision of promoting good health and a good quality of life through the effective management of noise within the context of Government policy on sustainable development.

This long-term vision is supported by the following aims:

Through the effective management and control of environmental, neighbour and neighbourhood noise within the context of Government policy on sustainable development to:

- a) avoid significant adverse impacts on health and quality of life;
- b) mitigate and minimise adverse impacts on health and quality of life; and
- c) where possible, contribute to the improvement of health and quality of life.

2.2 ETSU-R-97 – The Assessment & Rating of Noise from Windfarms ^[2]

Noise from wind turbines in the UK is assessed in accordance with the Department of Trade and Industry publication ETSU-R-97 'The Assessment and Rating of Noise from Windfarms' (ETSU-R-97). The Institute of Acoustics' publication 'A Good Practice Guide to The Application of ETSU-R-97 to the Assessment and Rating of Wind Turbine Noise' has been fully endorsed by the UK document and is as important in planning terms as ETSU-R-97. The Good Practice Guide provides clarity on the use of ETSU-R-97 and has removed some of the uncertainty and potential for technical dispute relating to wind farm/turbine noise impact assessment.

ETSU-R-97 defines minimum daytime and night-time absolute noise limits (unrelated to background noise levels) and an assessment methodology relative to the background noise level (whichever is greater). ETSU-R-97 indicates that for the protection of sleep of occupants within buildings an external free-field level of 43 dB LA₉₀ is appropriate when background noise levels (LA₉₀) are low. When background noise levels are sufficiently high, then the noise limits are set to the prevailing background + 5 dB, in the same manner as that used for the amenity hours. The day amenity hours noise limits have been set in ETSU-R-97 on the basis of protecting the amenity of residents whilst outside their dwellings in garden areas. The daytime amenity noise limits are formed in two parts: Part 1 is a simple relationship between the prevailing background noise level (with wind speed) with an allowance of +5 dB; and Part 2 is a fixed limit during periods of quiet. ETSU-R-97 describes three criteria to consider when determining the fixed part of the limit in the range of 35 dB to 40 dB LA₉₀, all of which should be considered. They are:

- a) the number of noise-affected properties;
- b) the potential impact on the power output of the wind farm; and
- c) the likely duration and level of exposure.

As the noise level emitted from wind turbines varies according to wind speed it is necessary to measure the background noise level at each receptor over a range of wind speeds and assess the noise impact over the range of operational wind speeds of the turbines.

The night-time hours are defined as: 23:00 – 07:00 hrs and the amenity hours are defined as: 18:00 – 23:00 hrs Monday – Friday; 13:00 – 18:00 hrs Saturday, and 07:00 – 18:00 hrs Sunday. The remaining hours corresponds to the daytime period.

2.3 Professional Practice Guidance on Planning & Noise (ProPG) ^[3]

ProPG states: *“Noise can have a significant effect on the environment and on the health and quality of life of individuals and communities. Noise can interfere with residential and community amenity and the utility of noise-sensitive land uses. Noise exposure can lead to a range of adverse effects including sleep disturbance and annoyance. There is evidence that exposure to aviation noise while at school can impair cognitive learning in children. It is also agreed by many experts that there is an association between long term exposure to environmental noise and chronic health effects. For example, associations have been found between long term exposure to transport noise, particularly from aircraft and road traffic, and an increase in the risk of cardiovascular effects (heart disease and hypertension).*

*For these reasons, **noise is a material consideration in the planning process and a key aspect of sustainable development. Noise must therefore be given serious attention when new developments might create additional noise** and when new developments would be sensitive to prevailing acoustic conditions.”*

ProPG also provides advice for Local Planning Authorities (LPAs) and developers, and their respective professional advisers. It aims to complement Government planning and noise policy and guidance. In particular, it strives to:

- a) advocate full consideration of the acoustic environment from the earliest possible stage of the development control process;
- b) encourage the process of good acoustic design in and around new residential developments;
- c) outline what should be taken into account in deciding planning applications for new noise-sensitive developments;
- d) improve understanding of how to determine the extent of potential noise impact and effect; and
- e) assist the delivery of sustainable development.

ProPG also states: *“The noise risk assessment may be based on measurement or prediction (or a combination) as appropriate and should aim to describe noise levels over a **“typical worst case” 24-hour day either now or in the foreseeable future.***

2.4 WHO: Environmental Noise Guidelines for Europe (2018) ^[4]

Noise is an underestimated threat that can cause a number of short and long-term health problems, such as sleep disturbance, cardiovascular effects, poorer work and school performance, hearing impairment, etc.

The World Health Organization (WHO) Environmental Noise Guidelines for the European Region provide guidance on protecting human health from harmful exposure to environmental noise from various sources: transportation (road traffic, railway, and aircraft) noise, wind turbine noise and leisure noise. This document was created to support the legislation and policy-making process on local, national, and international level. They therefore focus on the most used noise indicators L_{den} and/or L_{night} . The L_{den} and L_{night} indicators are those generally reported by authorities and are widely used for exposure assessment in health effect studies.

2.5 Consultation

Nottingham City Council's EHO was consulted prior to undertaking the assessment and requested that the noise assessment should cover all operational wind speeds for the VAWT and noted that the turbine can operate at much higher wind speeds than 10 m/s (up to 20 m/s?) and although localized aerodynamic noise (at the sensitive receptors) might mask some frequencies there may be some frequencies when the VAWT becomes noticeable/intrusive at the noise sensitive receptor.

In the consultation response it was also stated that Nottingham City Council usually specify a 'no increase in background noise levels' for plant and equipment being installed in the city to minimise 'background noise creep'. Acknowledging the variability of noise from such a dynamic system it was suggested that the acceptance criteria should be 'Noise from the proposed turbine, calculated in terms of $LA_{eq,1min}$ outside the nearest noise-sensitive premises, shall not exceed the background noise level, measured in terms of $LA_{90,1min}$, by more than 1dB(A) at all operational wind speeds, up to the VAWT's designed cut-out wind-speed.'

3. Description of the sites

For the NIA two separate locations have been assessed for their suitability: Option A (near the Main Car Park) towards the Northeast and Option B (near Erasmus Darwin Building) to the Southwest. The existing noise and weather conditions were assessed at both sites using two Type 1 Sound Level Meters and two Weather Stations at locations near the closest Noise-Sensitive Receptors (NSRs) to each Site. In addition, short duration attended measurements were undertaken in two further locations to the southeast of the Campus. Detailed information regarding the measurements is presented in Chapter 4 – Baseline Conditions.

Both proposed sites for the new wind turbine are located inside the Nottingham Trent University (NTU), Clifton Campus perimeter. The application areas have differing characteristics, which are detailed below.

3.1 Application Site - Option A

Site A is located on the top left corner area of the Clifton Cricket Ground shown to the southwest of the main car park in the image below (Figure 1).

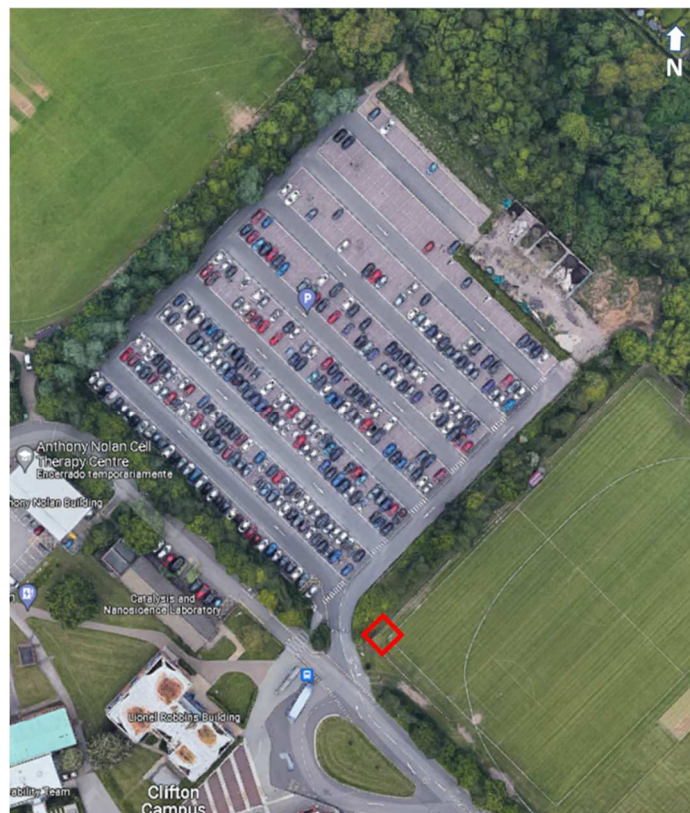


Figure 1 - Proposed Location for the Wind Turbine - Site A.

The closest NSRs are located to the North-East at around 190 m from the proposed installation location on Fleam Rd. The main buildings of the NTU Clifton Campus are located to the West and Southwest of the site under consideration, with Halls of Residence located approximately 90 m to the Southwest.

The ambient noise environment observed on site was primarily influenced by road traffic from the A453. Birdsong was also clearly audible, along with occasional aircraft noise.

3.2 Application Site – Option B

Option B is located towards the southern boundary of the campus near the South Gate Car Park Area (Figure 2).

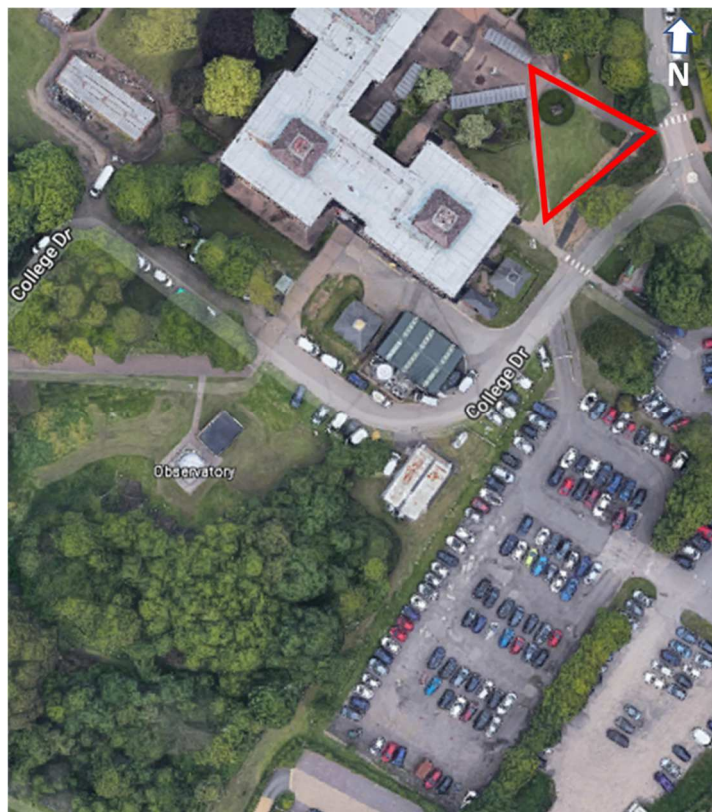


Figure 2 - Proposed Location for the Wind Turbine - Site B.

The closest NSRs are located 150 m to the Southwest (Village Road), and 175 m to the South (Grasby Walk) of the proposed Site. Nottingham Trent University owned houses on College Drive lie approximately 130-185 m to the West of the proposed site.

The main buildings of the NTU – Clifton Campus are located very close to the North and to the East of Site B. A rugby pitch is located to the South of the proposed site.

Again, the ambient noise environment observed on site was influenced mainly by road traffic on the A453 and from a fixed plant installed nearby to the southwest within the campus as well as birdsong and occasional aircraft noise.

4. Baseline Conditions

NSRs are defined as places which are potentially sensitive to noise such as residential dwellings and places where people may reside overnight, such as hotels and hospitals. Other examples include schools, community facilities, places of worship, designated areas, public parks and gardens, and public rights of way.

ETSU-R-97 proposes that measured $LA_{90,10\text{-minute}}$ noise levels and average 10 minute wind speed data at 10 m height are plotted on a scatter plot.

For these reasons, the background noise measurements were undertaken in locations near these NSRs to obtain the Background Noise Level (BNL), and close enough to the installation area of the wind turbine to obtain the wind conditions of the proposed site. For the purposes of this assessment, residential buildings under the control of Nottingham Trent University such as Halls of Residence have not been considered as NSRs as agreed with the client. However, some consideration to the potential effects to these premises will be given in Chapter 5.

Unattended continuous measurements were undertaken between the 21st and the 26th of April 2022 at locations which best represent the nearest NSR's to sites A and B. Attended short-time noise measurements were also undertaken on Saturday 23rd and Sunday 24th of April 2022 for periods of time between 30 and 60 minutes each.

The setup and operation of all the equipment was conducted by consultants certified as competent in environmental noise monitoring, and in accordance with the principles of BS 7445: Description and measurement of environmental noise^[5].

The equipment used for measuring sound pressure levels, including microphone(s), cable(s), windscreen(s), recording devices and other accessories conform to BS EN 61672-1: Electroacoustics. Sound level meters. Specifications^[6]. For these assessments, Class 1 Sound Level Meters (SLM) and two weather stations were used. The weather stations were mounted on 10-meter height masts. The noise measuring equipment used in the survey is summarised as follows:

- a) Cassella CEL-633C (Serial Number: 0939674 (calibrated in May 2021));
- b) Type 1 microphones MK-224;
- c) Casella Pre-amplifier CEL-495;
- d) Casella Cel CEL-120/2 Sound Level Calibrator 114dB 1kHz;
- e) Type 1 Sound Level Meters Fusion 4G (Serial Numbers: 14154 and 14157, calibrated in October 2021); and
- f) Calibrator CAL31 (Serial number 82830, calibrated in January 2022).

All calibration certificates are available on request.

Noise monitoring equipment was set up at two different locations (Figures 3 & 4) with the microphone set at a height of 1.5 m above the ground and sited at least 3.5 m from the nearest reflecting surface.

The noise measuring equipment used during the surveys were field calibrated at the start and end of each measurement. A drift of less than 0.5 dB was observed in all field calibrations throughout all the noise surveys.

The weather station was installed on the top of the 10 m height mast. The weather station equipment used were the following:

- a) Vaisala WXT532 which measure the following parameters: wind speed (m/s) and wind direction (degrees); and
- b) Vaisala WXT536 which measure the following parameters: wind speed (m/s), wind direction (degrees), rain intensity (mm/h), atmospheric pressure (hPa), temperature (°C), and humidity rate (%).

Sections 4.2 and 4.3 summarises the long-term (between 21st and 26th of April 2022) background conditions at the monitoring sites used to represent the nearest NSR's to Sites A and B, respectively. Section 4.4 summarises the short-time noise attended noise measurements undertaken over the weekend of 23rd and 24th of April 2022.

Section 4.5 presents the acoustic characteristics of the proposed wind turbine.

4.1 Weather Conditions

The weather throughout the survey period remained dry with only small periods of precipitation on 25th April between 15.00 – 17.00h. The wind direction was predominantly a north-easterly wind throughout the survey with mean wind speeds variable throughout with gusting of up to 15 m/s. Blustery conditions were commonplace during the daytime usually settling down during the evenings with calm settled nights. Further details of the weather conditions recorded on site are provided in Tables 1 and 2 and in the wind-direction charts in Appendix B.

While wind conditions throughout the survey were north-easterly, when considering the noise environment and the dominance of road traffic from the A453 to the east and the absence of any notable noise sources to the northeast and southwest, it was considered that there would unlikely be any significant variation in background noise levels as a result of a change of wind direction to the prevailing south westerly.

The average wind speeds at Site B were higher when compared to the average wind speeds in Site A. This is likely to be due to the presence of a tall line of trees to East of Site A. whereas the upwind approach to the monitoring location at Site B was much more open.

4.2 Background conditions - Site A

Figure 3 shows the location and the setup installed at the unattended monitoring location used to represent the nearest NSR's to Site A.

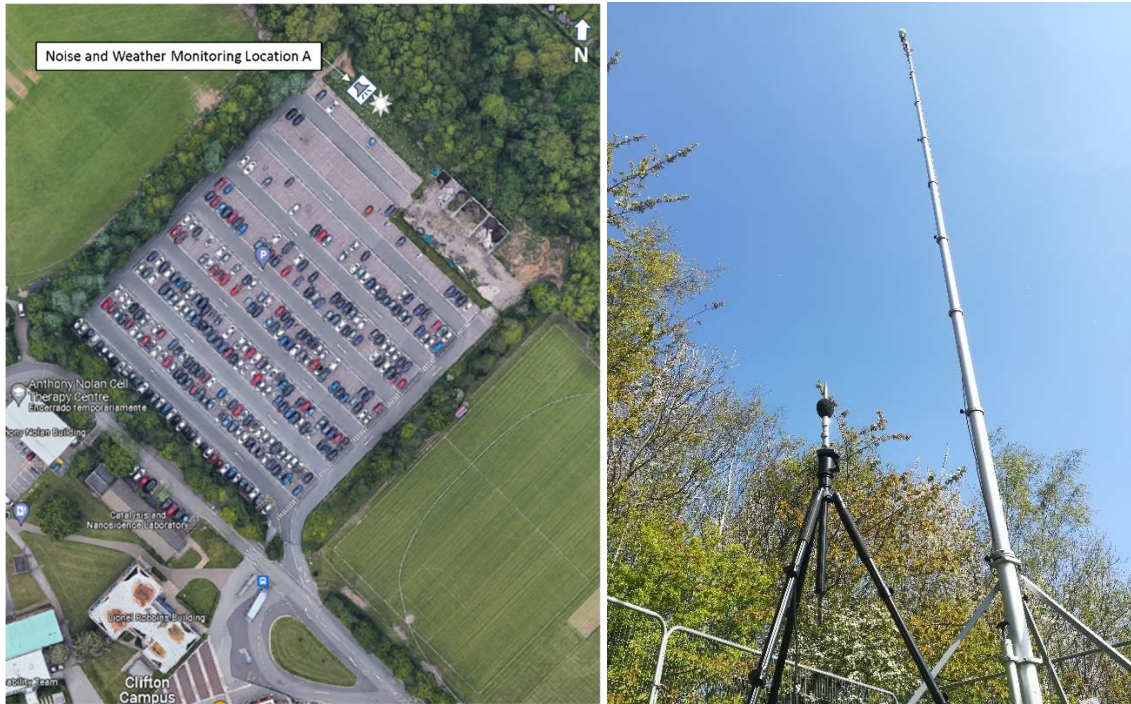


Figure 3 - Noise and weather monitoring at Site A.

The closest NSR lies approximately 75 m from the monitoring location site A on Fleam Rd to the Northeast. The A453 is located approximately 225 m to the East of the monitoring location. A summary of the survey results is presented in Table 1.

Table 1 - Summary of the average results of the noise and weather surveys at Site A.

Days	Period	Aver. LAeq (dB(A))	Aver. La90,10min (dB(A))	Aver. Wind Speed (m/s)	Aver. Wind Direction (°)	Aver. Rain Intensity (mm/h)	Aver. Atmospheric Pressure (hPa)	Aver. Temperature (°C)	Aver. Humidity Rate (%)
21 st – 22 nd April 2022	Daytime (14h40 – 18h00)	51.5	48.6	2.2	60.1	0	1006	15.6	43.3
	Amenity hours (18h00 – 23h00)	48.8	45.9	1.6	54.5	0	1007	11.3	59.2
	Night-time (23h00 – 07h00)	44.7	40.9	1.1	43.5	0	1005	7.4	86.5
22 nd – 23 rd April 2022	Daytime (07h00 – 18h00)	52.5	49.7	2.5	55.8	0	1003	12.8	57.5
	Amenity hours (18h00 – 23h00)	49.3	46.6	1.8	51.0	0	1002	10.0	64.8
	Night-time (23h00 – 07h00)	44.6	41.1	1.3	43.8	0	1001	8.0	88.8

23 rd – 24 th April 2022	Daytime (07h00 – 13h00)	50.3	47.5	1.7	48.6	0	1000	10.8	79.4
	Amenity hours (13h00 – 23h00)	49.8	47.2	2.0	51.3	0	1000	11.7	65.7
	Night-time (23h00 – 07h00)	44.7	40.8	1.2	41.4	0	1002	7.3	87.8
24 th – 25 th April 2022	Amenity Hours (07h00 – 23 h00)	49.0	46.0	1.6	48.5	0	1005	11.7	59.7
	Night-time (23h00 – 07h00)	44.0	40.0	0.8	29.8	0	1008	5.9	82.7
25 th – 26 th April 2022	Daytime (07h00 – 18h00)	49.4	46.5	0.8	56.0	0.02	1010	9.5	70.7
	Amenity hours (18h00 – 23h00)	47.7	45.1	0.7	54.0	0	1012	9.3	72.9
	Night-time (23h00 – 07h00)	44.4	39.1	0.5	34.9	0	1014	6.7	89.7

4.3 Background conditions - Site B

Figure 4 shows the location and the setup installed at the unattended monitoring location used to represent the nearest NSR's to Site B. The closest NSR lies approximately 25 m South of the monitoring location (2 Village Rd) with the A453 located approximately 85 m to the East.

A summary of the survey results is presented in Table 2.



Figure 4 - Noise and weather monitoring at Site B.

Table 2 - Summary of the average results of the noise and weather surveys at Site B.

Days	Period	Aver. LAeq (dB(A))	Aver. La90,10min (dB(A))	Aver. Wind Speed (m/s)	Aver. Wind Direction (°)
21 st – 22 nd April 2022	Daytime (16h00 -17h50)	57.7	53.4	4.6	58.7
	Amenity hours (18h00 – 23h00)	55.3	51.3	3.6	50.6
	Night-time (23h00 – 07h00)	51.8	46.2	2.7	32.7
22 nd – 23 rd April 2022	Daytime (07h00 – 18h00)	58.5	54.8	5.0	53.3
	Amenity hours (18h00 – 23h00)	56.6	52.4	4.1	48.1
	Night-time (23h00 – 07h00)	52.1	46.5	3.2	34.1
23 rd – 24 th April 2022	Daytime (07h00 – 13h00)	58.0	54.0	4.4	44.4
	Amenity hours (13h00 – 23h00)	57.2	53.0	4.9	49.5
	Night-time (23h00 – 07h00)	51.3	45.7	2.9	31.5
24 th – 25 th April 2022	Amenity Hours (07h00 – 23 h00)	56.4	52.3	4.2	45.6
	Night-time (23h00 – 07h00)	50.3	44.9	1.6	93.5
25 th – 26 th April 2022	Daytime (07h00 – 18h00)	54.5	51.1	1.9	73.2
	Amenity hours (18h00 – 23h00)	53.7	50.4	1.8	55.6
	Night-time (23h00 – 07h00)	49.5	44.0	1.4	38.9

4.4 Short duration attended noise surveys at other NSR locations

Short duration noise surveys were also conducted at 15 Glapton Lane, NG11 8DE, and 71 Rivergreen, NG11 8FU (Figure 5) between 18h00 and 01h30 on 23rd and 24th of April 2022 (during the amenity hours and the night-time period) by using the Casella CEL-633C Type 1 SLM.

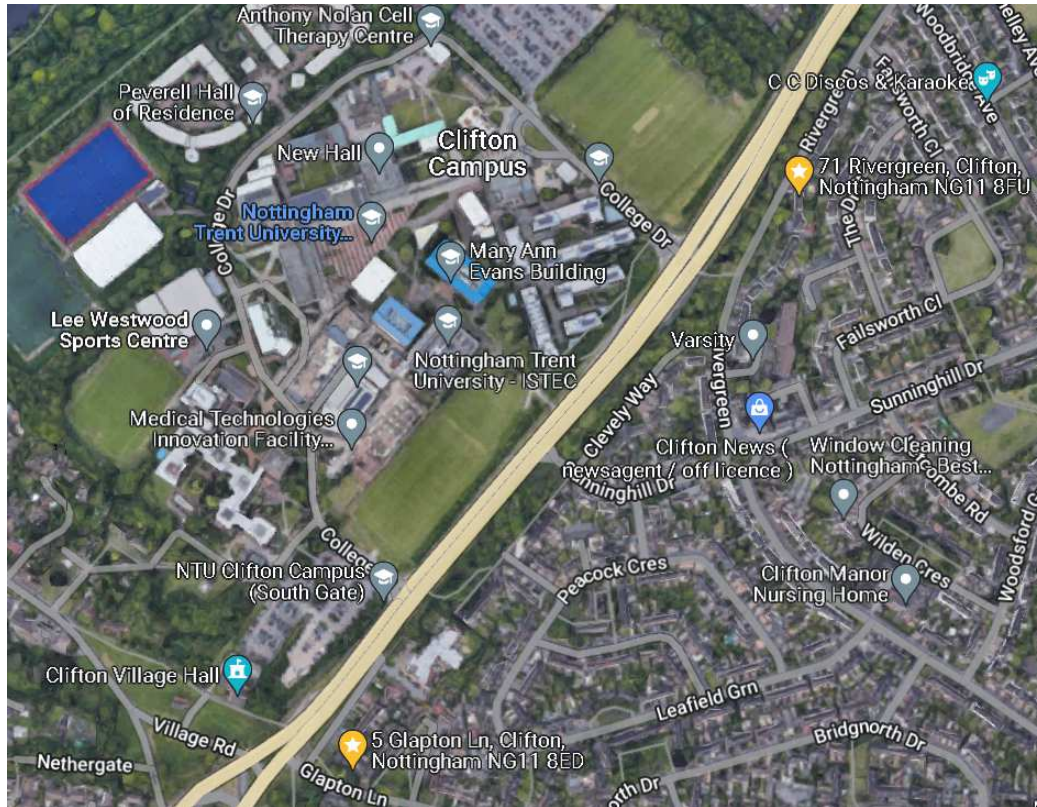


Figure 5 - Attended Noise Surveys Locations: 5 Glapton Ln and 71 Rivergreen.

In both locations the existing noise environment is dominated by road traffic noise due to the proximity of A453 Road (less than 50 m). The summary of the results for both locations are represented in Table 3.

Table 3 - Summary of short-time attended noise surveys at. 15 Glapton Ln and 71 Rivergreen, Clifton.

Location	Day and time	Duration	LA _{eq,T}	LA _{90,T}
15 Glapton Ln, NG11 8DE	Saturday 23 rd at 18:17	1 Hour	61.7	50.1
	Saturday 23 rd at 23:07	30 Minutes	52.4	46.8
	Sunday 24 th at 00:27	30 Minutes	50.9	42.5
71 Rivergreen, NG11 8FU	Saturday 23 rd at 19:28	1 Hour	61.4	55.3
	Saturday 23 rd at 23:48	30 Minutes	56.8	48.5
	Sunday 24 th at 01:09	30 Minutes	55.7	45.8

4.5 Wind Turbine Acoustics Characteristics

The proposed wind turbine to be installed it's the Qr6 VAWT from the manufacturer Quiet Revolution.

The Qr6 VAWT has the capacity to produce an electrical power of up to 7kW. The Qr6 VAWT has a cut in speed of 1.5 m/s (3.35 mph) and will function making a positive contribution down to 1.1 m/s (2.5 mph) and cuts out to protect itself at 20 m/s (45 mph) (Figure 6). Most calm days in the UK can be considered to still have 6 mph to 10 mph wind speeds on the ground which increases rapidly on a mast at 20 m.

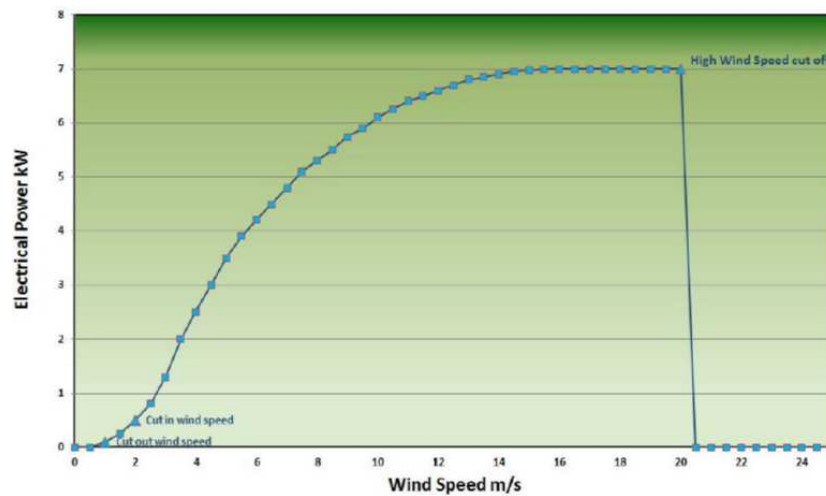


Figure 6 – Qr6 VAWT Power Curve.

The noise data provided by the manufacturer is displayed in Table 4 below for a wind speed of 8 m/s at the rotor centre height.

Table 4 - Qr6 VAWT derived noise emission and noise emission for a wind speed of 8m/s at the rotor center height.

PARAMETER	SYMBOL	VALUE
Apparent Emission Sound Power Level (dB(A) re 10^{-12} W)	$L_{Wd,8m/s}$	86.5
Combined Uncertainty (68% confidence level) (dB)	σ	1.9
95% Confidence Limit (dB)	1.645σ	3.1
Noise Slope at 8 m/s (dB/m/s)	S_{dB}	2.38
Declared Apparent Emission Sound Power Level, (dB(A) re 10^{-12} W)	$L_{Wd,8m/s}$	90
Immission Sound Pressure Level at 60 m at 8 m/s (dB(A) re 20 μ Pa)	$L_{p,60m}$	47
Immission Sound Pressure Level at 25 m at 8 m/s (dB(A) re 20 μ Pa)	$L_{p,25m}$	54

Further data was provided by the manufacturer which certified the relationship between

the noise generated by the VAWT over a range of mean wind speeds during controlled test conditions. The relationship derived shows a linear relationship up to the limit of the test conditions (~11m/s). The derived relationship was then analysed for deviation over the range of results obtained and a declared relationship with 95% confidence level has been provided as below:

$$Y = 2.38x + 33.92$$

Where Y = Audible noise level (dB) and X = Mean Wind Speed at hub height.

The relationship was obtained from noise measurements taken at a slope distance of 32.2 m downwind from the turbine.

The relationship derived is later used to determine the predicted noise levels of the VAWT for each site.

5. Assessment Methodology

The methodology employed to determine the Noise Impact Assessment (NIA) of the proposed VAWT is summarised below:

- a) Analyse and filter collected noise / wind speed data in accordance with the IOA Good Practice Guide, to derive representative relationship between BNL and Mean Wind Speed for each location.
- b) From the derived relationships, define the noise limit in accordance with the guidance in ETSU-R-97.
- c) Plot noise/wind speed level characteristics of new VAWT and overlay with derived BNL/Mean Wind Speed relationship and the defined noise limit for each site to determine compliance.
- d) Recommendation of mitigation measures, where necessary, to comply with the requirements and achieve compliance.

5.1 Data Analysis & Filtering

In accordance with ETSU-R-97 the purpose of data analysis is to provide a representative background noise level across a range of wind speeds for the Amenity and Night-time hours and thereby help define appropriate noise limits for the proposed VAWT. ETSU-R-97 states that the removal of atypical noise sources should be undertaken, and that consideration should also be given to removal of periods that may cause a marked increase in noise such as the dawn chorus. Furthermore, sites which are particularly affected by traffic noise should be carefully reviewed where noise levels can vary significantly.

From reviewing the variation in noise levels at both locations where measurements were recorded, it is noted that during the night-time, noise levels start to increase significantly from 5 am which is likely to be due to a combination of the dawn chorus and increasing road traffic noise levels due to the presence of the nearby A453. As such the periods from 5 am to 7 am have been filtered out of the night-time noise measurements to ensure that the background noise levels used in the determination of appropriate limits reflects the worst case and is typical of night-time levels during the quieter period of the night-time.

Similarly, a review was undertaken of the amenity and daytime periods which revealed relatively consistent noise levels throughout the day typical of expected noise levels dominated by road traffic. Noise levels in the evening were found to gradually decrease as expected for such a situation.

5.2 Defining the Relationship between Background Noise and Mean Wind Speed

To derive a relationship between background noise level and wind speed, the results of the filtered data were plotted for the night-time, amenity, and daytime periods. To have confidence in any derived relationship it is necessary to ensure that there is a wide data

set. From the plotted filtered night-time results, it was found that the plot of results of background noise levels against wind speed showed a poor relationship between the two. This is likely to be for two reasons. Firstly, it is not uncommon to find poor correlation where results are being affected by other factors such as traffic noise as in this case and secondly the wind speed range during the night-time was very limited compared with the daytime periods when wind speeds were much more variable. During the period of measurement, while the weather conditions during the day would be considered 'blustery' with variable wind speeds, the weather during the night remained calm with much lower wind speeds.

The plots of wind speed versus background noise during amenity periods proved to be variable too which is likely to be due to the periods used here with variable traffic conditions which likely to have significantly affected the results.

For both locations the most reliable relationship was derived between the background noise level and wind speed during the daytime for two main reasons. Firstly, traffic flows and therefore corresponding variation in background noise as a consequence of traffic flow was much less variable reducing its influence on the variation of background noise levels. Secondly, the wind speeds during the daytime period were much more variable and over a wider range than during other periods, enabling a better dataset from which to determine if a relationship between background noise and wind speed existed.

As a result, the plot of background noise levels with wind speed in the daytime enabled a relationship to be determined. The plot of the results shows a very clear trend to increased background noise levels with wind speed at both locations. The R^2 value which measures the strength of correlation showed a correlation level greater than 0.6 at Site B and greater than 0.8 at Site A. A truly perfect linear relationship would have an R^2 value of 1.0, while a poor relationship or correlation between the data sets would likely have an R^2 value much lower than 0.5.

The scattered plots for the Site A and Site B are described below for the daytime, amenity, and night-time periods.

Site A

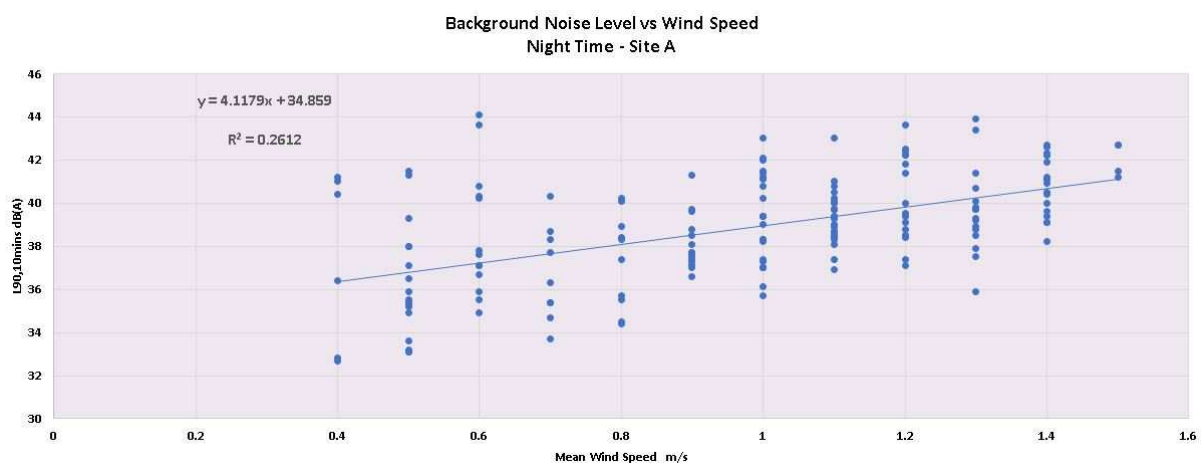


Figure 7 - BNL vs Mean Wind Speed for the night period at Location A.

The scatter plot in Figure 7 for the night-time period at Site A excludes the filtered-out periods between 5 am – 7 am. While the results indicate a general trend to higher background noise levels with higher mean wind speed, the strength of the relationship is poor with an R^2 value of 0.26. This is likely to be due to the influence of road traffic noise on the data and the small range of wind speed data during the night-time period.

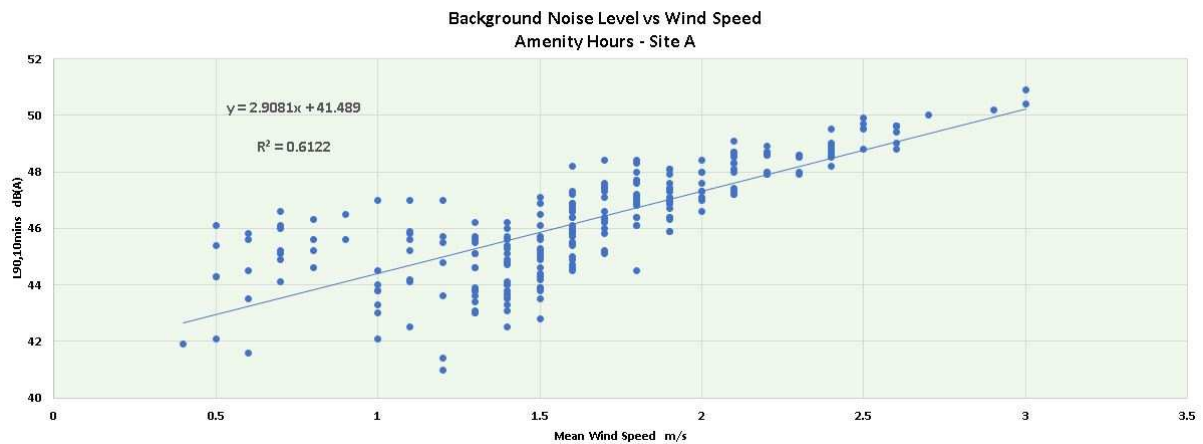


Figure 8 - BNL vs Mean Wind Speed for the amenity hours period at Location A.

The scatter plot in Figure 8 for the amenity hours at Site A provides a stronger correlation between background noise levels and wind speed with an R^2 value of 0.61. There is much more variance at lower mean wind speeds with improving correlation at higher wind speeds. The wind speed range is wider giving greater confidence in the results and appear to be less influenced by variations in road traffic noise at higher wind speeds. The recorded range of BNL's are high enough to avoid the need for any lower fixed limits to protect amenity.

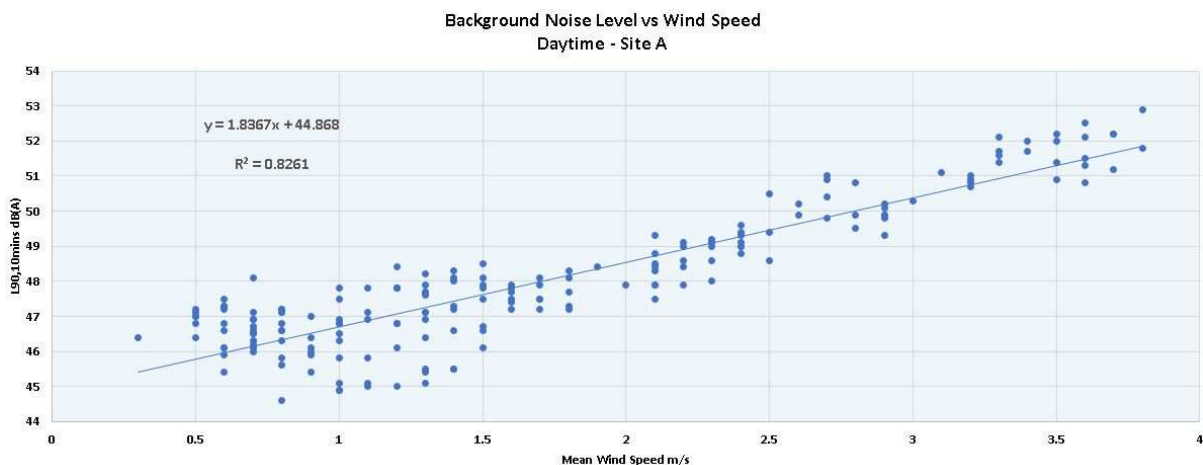


Figure 9 - BNL vs Mean Wind Speed for the daytime period at Location A.

The scatter plot in Figure 9 for the daytime period at Site A indicates a very strong relationship between background noise levels and mean wind speeds with an R^2 value of 0.83. Again, the greater variance occurs at lower wind speeds where variation in traffic

noise is likely to have more influence. The wind speed data is over a wider range than the other periods giving increased confidence in the relationship derived.

The relationships in all cases appear to be linear – suggesting a consistent step-change in background noise level with each incremental increase in mean wind speed. Examining the relationships for night-time, amenity hours and daytime indicates that the incremental increase is greatest during the night and lowest during the day for each incremental increase in mean wind speed. This is likely to be due to that fact that ambient noise levels are lowest during the night and highest during the day – meaning that wind speed has the greatest influence when the ambient noise from other sources is lowest.

One would also expect that if all other noise sources were removed, wind induced noise would be consistent throughout all periods of the day and night. The proposed approach in this case is to use the relationship derived for changes in noise levels during the day (the strongest correlation – but smallest incremental change in BNL with each incremental increase in mean wind speed) and apply it to the amenity hours and night-time noise profiles. This will provide a conservative and ‘worst case’ baseline from which to work from when determining the appropriate noise limits with which to overlay and compare the noise profile for the proposed VAWT and to determine compliance with the derived limits.

Site B

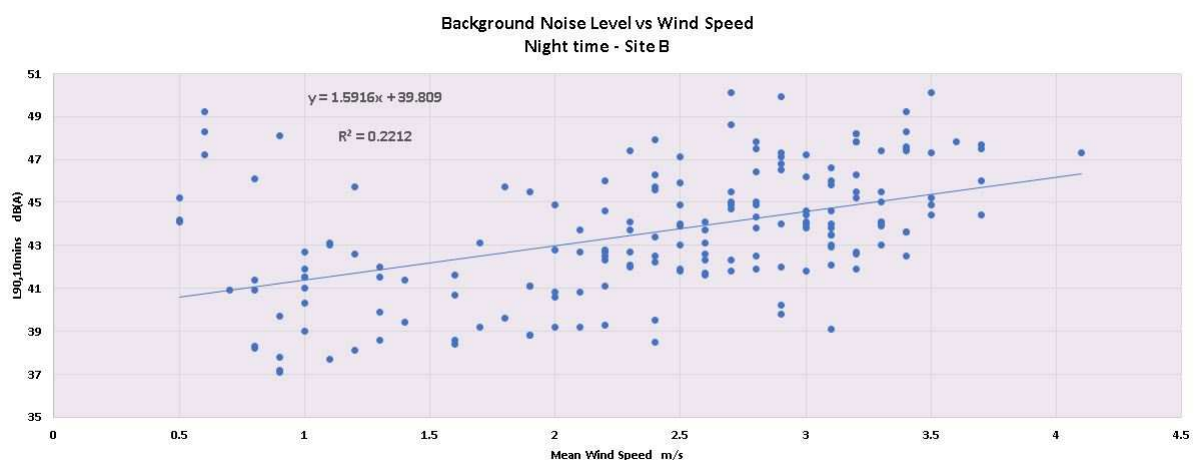


Figure 10 - BNL vs Mean Wind Speed for the night period at Location B.

Similarly, to Site A, the scatter plot in Figure 10 shows a poor relationship between background noise and wind speed during the night-time period. This is again likely to be due to the factors outlined previously with traffic noise variation of the measurement period having a greater influence and a more limited wind speed range compared to the amenity hours and daytime periods.

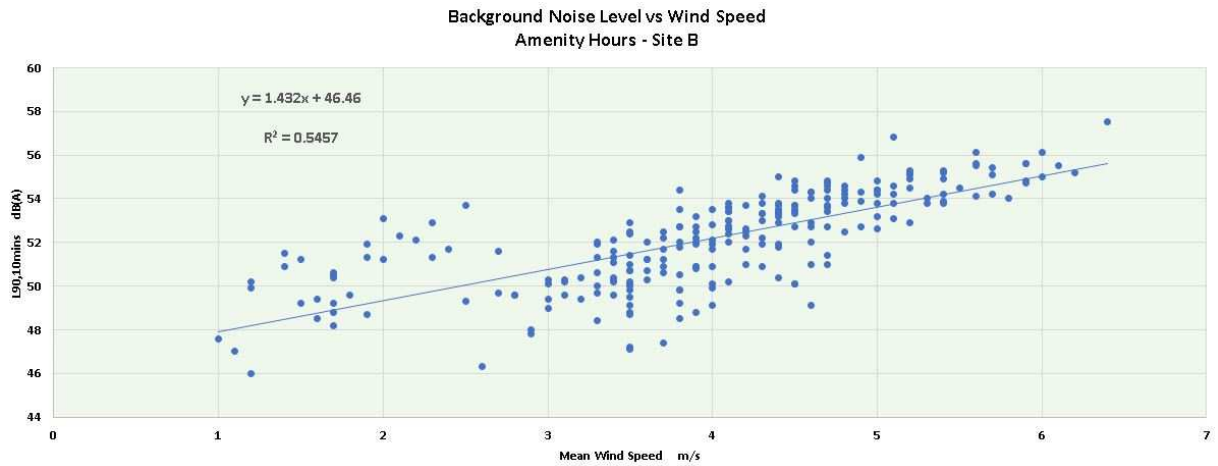


Figure 11 - BNL vs Mean Wind Speed for the amenity hours period at Location B.

Again, the scatter plot in Figure 11 for amenity hours at Site B indicates a stronger relationship between background noise levels and Mean Wind Speed with an R^2 value of 0.55, with the greatest variance occurring at lower wind speeds. The wind speed range is larger giving greater confidence in the relationship derived and appears to be less influenced by variations in road traffic noise at higher wind speeds. The recorded range of BNL's are high enough to avoid the need for any lower fixed limits to protect amenity.

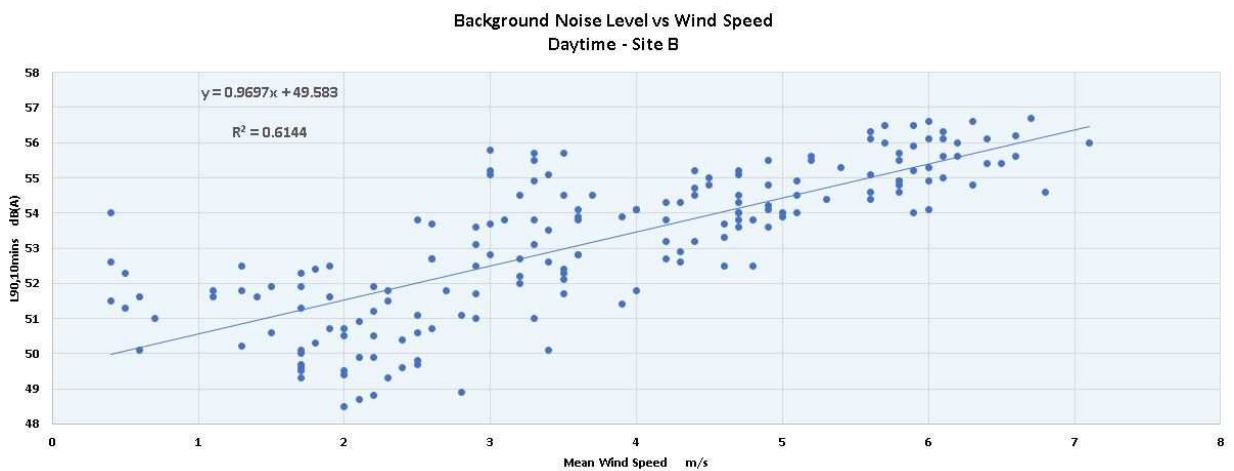


Figure 12 - BNL vs Mean Wind Speed for the daytime period at Location B.

The scatter plot in Figure 12 for daytime hours at Site B shows the strongest correlation between background noise level and mean wind speed with an R^2 value of 0.61. While not as strong as at Site A, probably due to its closer proximity to the A453, the relationship is still good and provides the strongest correlation of all three periods and has the largest captured wind speed range.

Again, the step change in background noise level with each incremental increase in mean wind speed according to each of the relationships derived is highest during the night-time

and lowest during the daytime. Therefore, using the daytime relationship with the strongest relationship between BNL and Mean Wind Speed and applying this to the other periods, provides a conservative and 'worst case' baseline for BNL's with which to compare the noise profile for the VAWT during each period.

5.3 Comparison of BNL derived profile and VAWT Noise Profile

Figures 13 to 18 show the relationship between the BNL and the noise profile of the VAWT corrected for the distance to the nearest NSR (located at 190 m from Site A and 150 m from Site B). The captured relationship between the BNL and mean wind speed is depicted by the solid grey line. The dashed grey line shows the projected change in BNL up to 12 m/s. However, as stated in ETSU-R-97, one should not assume that the relationship would remain true beyond the limit of data capture. As such the derived ETSU-R-97 noise limit does not extend above the limit of data capture for the BNL and is set in accordance with the ETSU-R-97 recommendation of $LA_{90}+5dB$. Figure 14 shows a fixed limit of 43dB $L_{90,10mins}$ within the lower wind speed range of 1-3m/s due to the BNLs at low mean wind speeds during the night, falling below 43dB.

The solid blue line shows the VAWT noise profile corrected for the slope distance which represents the distance between the central axis of the VAWT and the nearest NSR for the proposed location. The relationship has been extended up to 12 m/s. It should be noted that for the purposes of noise assessment, ETSU-R-97 states:

"(...) one should only seek to place limits on noise over a range of wind speeds up to 12m/s when measured at 10m height on the wind farm site. There are four reasons for restricting the noise limits to this range of wind speed:

- 1) Wind speeds are not often measured at wind speeds greater than 12m/s at 10m height.*
- 2) Reliable measurements of background noise levels and turbine noise will be difficult to make in high winds*
- 3) Turbine manufacturers are unlikely to be able to provide information on sound power levels at such high wind speeds for similar reasons*
- 4) If a wind farm meets noise limits at wind speeds lower than 12m/s it is most unlikely to cause any greater loss of amenity at higher wind speed"*

The manufacturer data for the proposed VAWT does not provide any data beyond 12 m/s and so for the reasons outlined above, the assessment cannot consider wind speeds higher than 12 m/s. While it has not been possible to assess noise levels from the VAWT over the full operational range of wind speeds in accordance with the wishes of the Nottingham City EHO, as stated in point 4 above, it is considered unlikely that any greater loss of amenity will occur at higher wind speeds if the noise limits for up to 12 m/s can be met.

Site A – Slope distance = 190m to nearest NSR

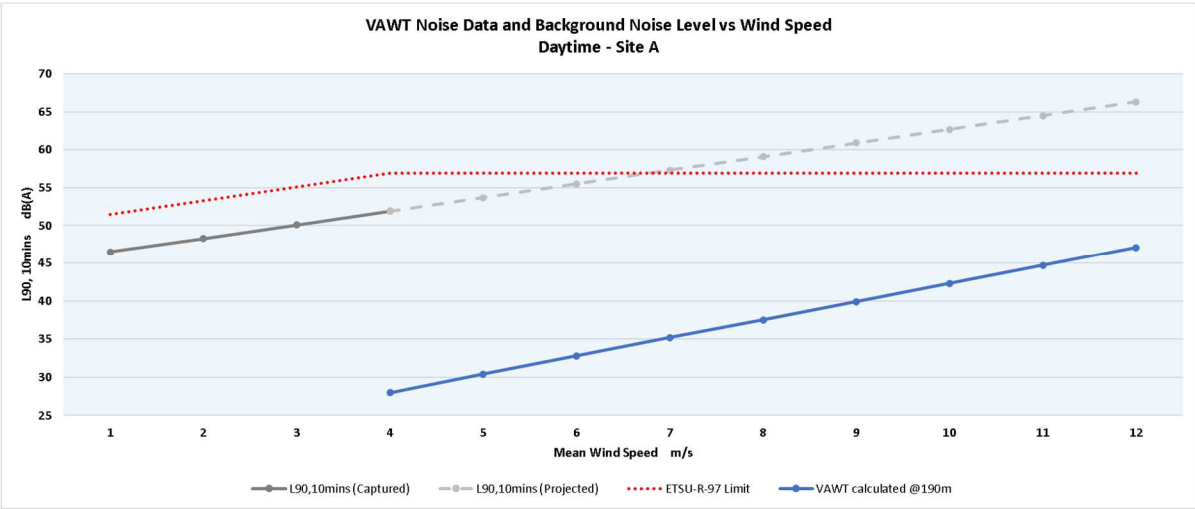


Figure 13

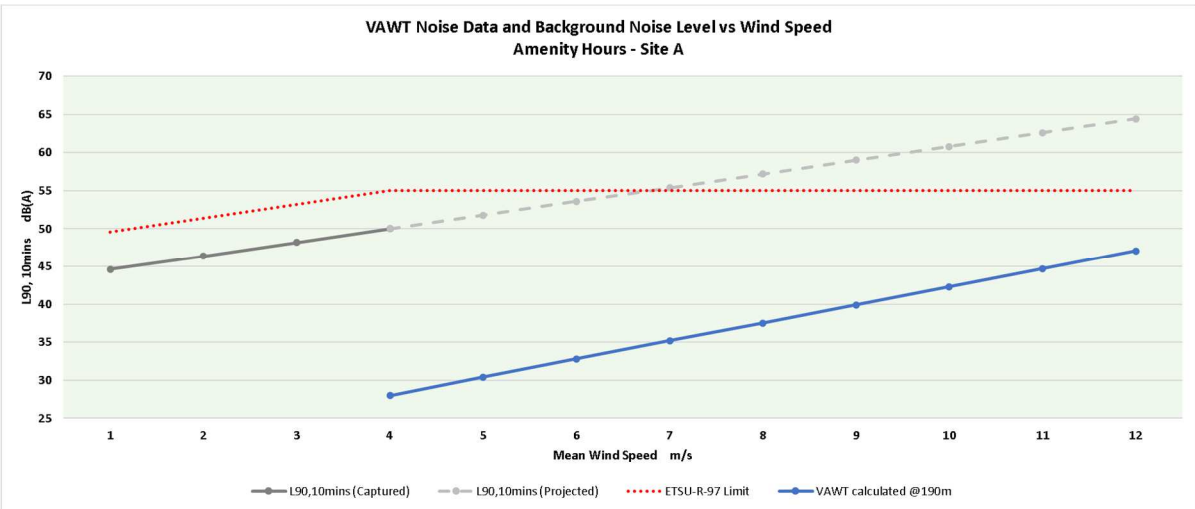


Figure 14

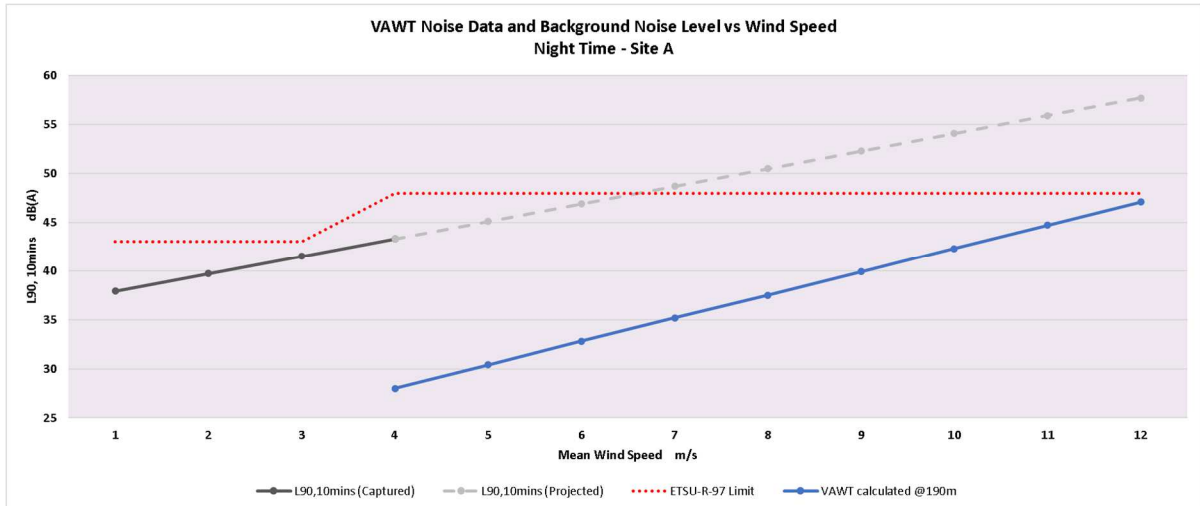


Figure 15

For all periods, daytime, amenity hours and night-time, the projected noise profile for the VAWT at 190 m remains below the ETSU noise limit line for the limit of data capture (4m/s).

As stated earlier, it is likely that the actual BNL for wind speeds above 4 m/s would be higher than the ETSU limit, and so it is with a high degree of confidence that the BNL at the receptor locations would not be exceeded. It should also be noted that the nearest NSR to the proposed location of the VAWT is located in closer proximity to the A453, than the location used for the measured noise survey and so would likely have a higher BNL than the profile shown, giving further confidence that the presented assessment depicts a worst-case scenario.

LOCATION B – Slope distance = 150m to nearest NSR

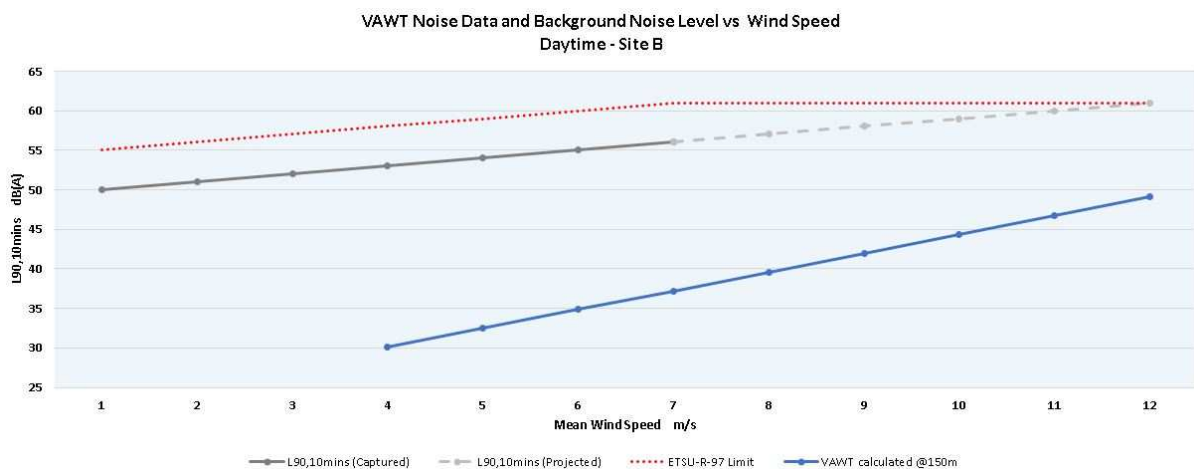


Figure 16

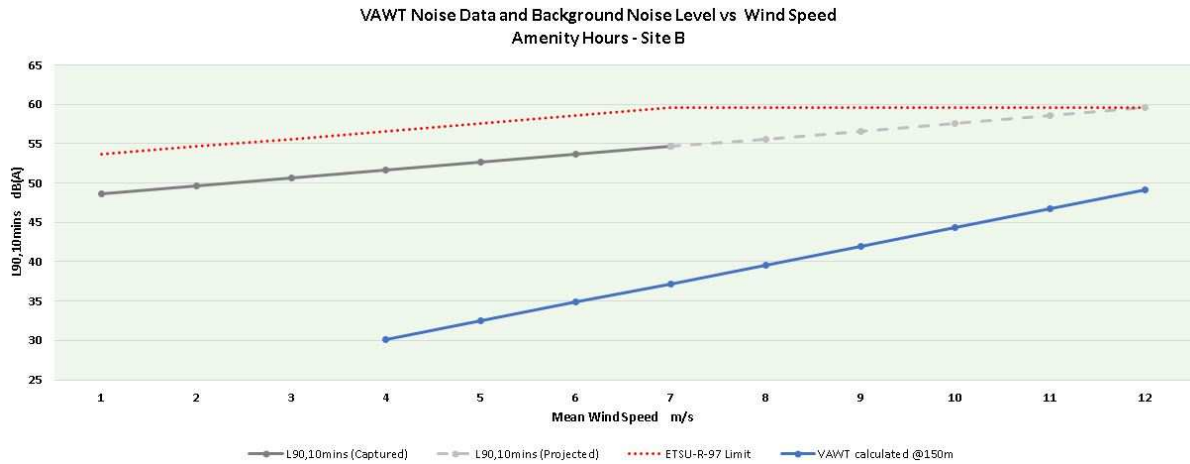


Figure 17

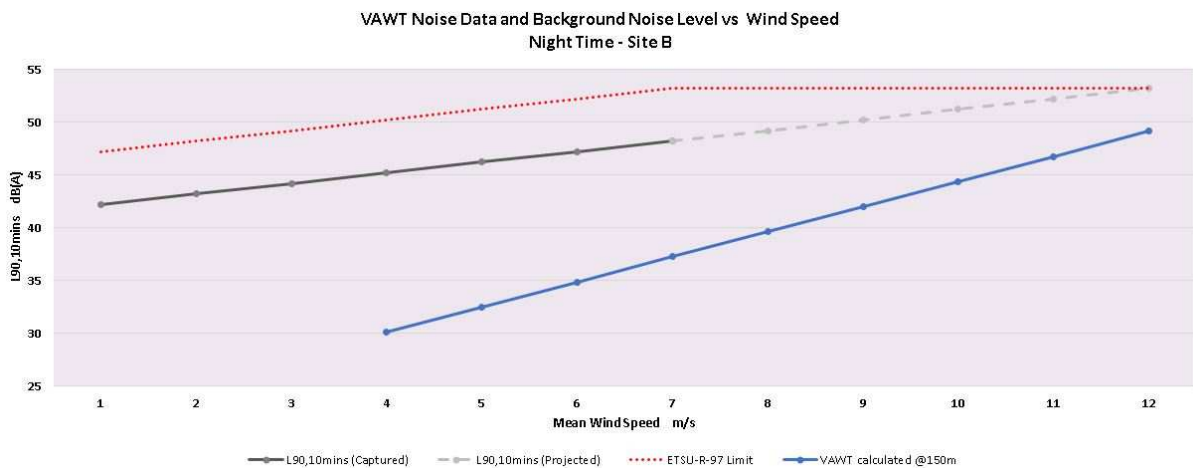


Figure 18

For all periods, daytime, amenity hours and night-time, the projected noise profile for the VAWT at 150 m remains below the ETSU noise limit.

Again, as stated earlier, it is likely that the actual BNL at winds speeds greater than 7 m/s would be higher than the ETSU limit based on a wind speed data capture range of 7 m/s, and so once again it can be said with a high degree of confidence that the BNL at the receptor locations would not be exceeded.

The EHO consultation response specifically requested that the noise levels from the VAWT should not exceed the BNL by greater than 1dB.

Taking the BNL ($LA_{90,10mins}$) and comparing directly with the predicted noise level of the VAWT, the predicted noise level at the highest assessed speed of 12 m/s during the night-time is as follows:

Site A: At 12m/s	Projected BNL	= 57.7 dB
	BNL at limit of data capture (4 m/s)	= 43.3 dB
	ETSU BNL Limit	= 48.0 dB
	NCC EHO Limit (Using ETSU Limit)	= 44.3 dB
	(Using projected BNL)	= 58.7 dB
	VAWT @ 190m	= 47.1 dB
Site B: At 12 m/s	Projected BNL	= 53.2dB
	BNL at limit of data capture (7 m/s)	= 48.2dB
	ETSU BNL Limit	= 53.0dB
	NCC EHO Limit (Using ETSU Limit)	= 49.2dB
	(Using projected BNL)	= 54.2dB
	VAWT @ 150m	= 49.1dB

From the above it can be deduced that while the BNL (based on limit of data capture) shows an exceedance of 2.8 dB at Site A, it can again be said with a high degree of confidence that the actual BNL at 12 m/s would be higher than the ETSU limit value based on the limited data capture upon which the ETSU limit has been derived. When comparing with the projected BNL the predicted noise level at 12 m/s is 11.6 dB lower. While the accuracy of the projected BNL cannot be relied upon, the actual BNL is likely to lie somewhere between the two values and would likely be higher than the ETSU limit by at least 2.8dB.

For Site B the above would also be true, however in this case the EHO limit derived from the ETSU limit has already been met.

NTU Student Accommodation

While not strictly considered as NSR's as they are under the control of NTU, the Halls of Residence are nonetheless occupied by rent paying students who reside in the premises throughout the year. Therefore, it is recommended that consideration is given to the potential noise impacts of the VAWT on these residents.

Site B does not have any Halls of Residence accommodation within the distances already outlined in the assessment and therefore no further consideration in relation to this site is required. Site A however has halls of residence located approximately 90 m to the Southeast from the proposed position of the VAWT (see Figure 19 below). Given the location of the residences are in much closer proximity to the A453, the BNL measurements in the location closest to Site B are considered to be a more representative proxy for these premises given the similar distance from the primary noise source of road traffic on the A453.



Figure 19 - Halls of residence located near the Site A.

Figure 20 below illustrates that for the most part, noise levels from the VAWT would be below the ETSU limit and projected BNL, however a minor exceedance occurs at 12m/s. Again, as stated earlier, it is likely that the actual BNL at winds speeds greater than 7 m/s would be higher than the ETSU limit based on a wind speed data capture range of 7 m/s, and so once again it can be said with a high degree of confidence that the BNL at the halls of residence would not be exceeded.

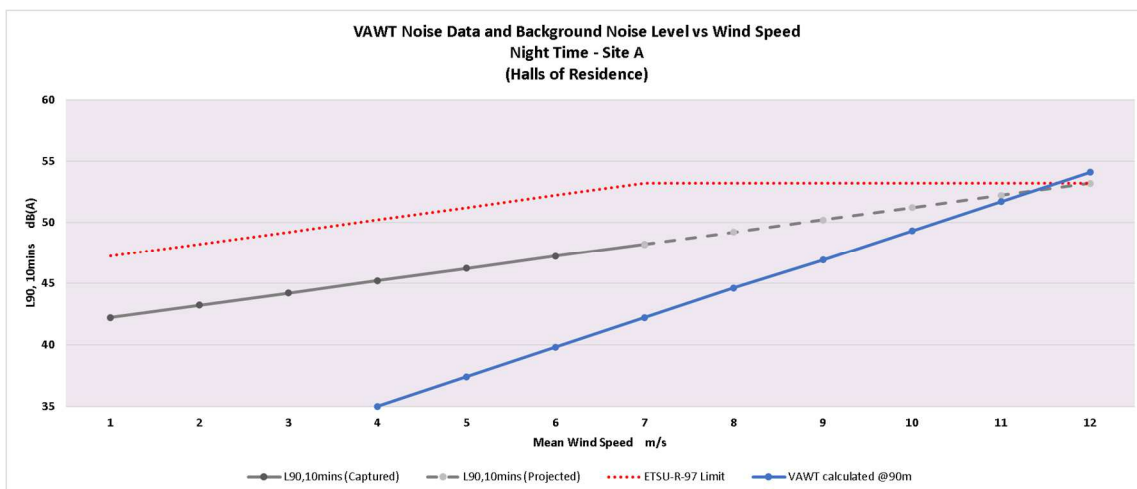


Figure 20

6. Conclusions and Recommendations

6.1 Conclusions

Two sites have been considered for a new VAWT installation at NTU's Clifton campus in Nottingham. Both sites have been assessed in accordance with the ETSU-R-97 guidance. The assessment included measurements of the background noise levels and mean wind speeds at two locations representative of the nearest NSR's to derive a relationship between BNL and mean wind speed in accordance with ETSU-R-97 guidance.

The relationships were then overlaid with the noise profile of the VAWT which have been corrected for the distance between the proposed VAWT locations and the nearest NSR's.

The assessment confirms that both locations would comply with the ETSU-R-97 guidance and so would be unlikely to generate noise complaints as a result of their installation at the nearest identified NSR's.

The VAWT can operate at a threshold wind speed of 20 m/s, however it's very likely that at high wind speeds, wind induced noise would dominate over the noise from the VAWT itself.

6.2 Recommendations

It is recommended that the VAWT is regularly serviced and maintained to ensure that the VAWT operates in compliance with the manufacturers declared noise data. Faulty bearings or damaged parts can lead to an imbalance causing vibration and corresponding higher noise levels or tonality that could cause annoyance. It is therefore recommended that a noise condition be imposed that requires the Operator to undertake regular maintenance and servicing of the VAWT.

It is also recommended that an "*in the event of a complaint*" noise condition be imposed such that in the event of a noise complaint which the LPA considers to be justified, that the Operator must demonstrate through site noise measurements that the VAWT is operating in compliance with the manufacturers noise data and that the ETSU noise limits as defined in ETSU-R-97 are complied with at all nearby residential receptors not under the control of NTU.

In the event that the VAWT is failing to comply with the ETSU guidance and/or manufacturers noise data, the Operator shall seek to repair/remedy the VAWT to achieve compliance and prove that the corrective action taken has achieved compliance through further measurements. Alternatively, the operator shall submit details to the LPA as to how the operation of the VAWT will be controlled/restricted to achieve compliance.

REFERENCES

- [1] Department for Environment, Food and Rural Affairs (DEFRA). Noise Policy Statement for England (NPSE), London, UK, March 2010.
- [2] The Assessment and Rating of Noise from Wind Farms, IOA Working Group on Noise from Wind Turbines ETSU-R-97, September 1996.
- [3] Working Group consisting of representatives of the Association of Noise Consultants (ANC), Institute of Acoustics (IOA) and Chartered Institute of Environmental Health (CIEH). Professional Practice Guidance on Planning & Noise (ProPG), May 2017.
- [4] World Health Organization (WHO). Environmental Noise Guidelines for the European Region, 2018
- [5] The British Standards Institution. BS 7445: Description and measurement of environmental noise, 2003.
- [6] The British Standards Institution. Electroacoustics. Sound level meters. Specifications, 2013.

APPENDICES

Appendix A –Terms and Definitions

Sound Pressure: Sound, or sound pressure, is a fluctuation in air pressure over the static ambient pressure.

Sound Pressure Level (Sound Level): The sound level is the sound pressure relative to a standard reference pressure of $20\mu\text{Pa}$ (20×10^{-6} Pascals) on a decibel scale.

Decibel (dB): A scale for comparing the ratios of two quantities, including sound pressure and sound power. The difference in level between two sounds s_1 and s_2 is given by $20 \log_{10} (s_1 / s_2)$. The decibel can also be used to measure absolute quantities by specifying a reference value that fixes one point on the scale. For sound pressure, the reference value is $20\mu\text{Pa}$.

A-weighting, dB(A): The unit of sound level, weighted according to the A-scale, which takes into account the increased sensitivity of the human ear at some frequencies. Noise Level Indices:

$L_{Aeq,T}$: A noise level index called the equivalent continuous noise level over the time period T , weighted according to the A-scale. This is the level of a notional steady sound that would contain the same amount of sound energy as the actual, possibly fluctuating, sound that was recorded.

$L_{Amax,T}$: A noise level index defined as the maximum noise level during the period T , weighted according to the A-scale. L_{max} is sometimes used for the assessment of occasional loud noises, which may have little effect on the overall L_{eq} noise level but will still affect the noise environment. Unless described otherwise, it is measured using the 'fast' sound level meter response.

$L_{A90,T}$ or BNL: A noise level index. The noise level exceeded for 90% of the time over the period T , weighted according to the A-scale. L_{90} can be considered to be the "average minimum" noise level and is often used to describe the background noise.

$L_{A10,T}$: A noise level index. The noise level exceeded for 10% of the time over the period T , weighted according to the A-scale. L_{10} can be considered to be the "average maximum" noise level. Generally used to describe road traffic noise.

The human ear can detect a very wide range of pressure fluctuations, which are perceived as sound. In order to express these fluctuations in a manageable way, a logarithmic scale called the decibel, or dB scale is used. The decibel scale typically ranges from 0 dB (the threshold of hearing) to over 120 dB. An indication of the range of sound levels commonly found in the environment is given in the following table.

Sound Level	Example of type of environment
0 dB(A)	Threshold of hearing
20 to 30dB(A)	Quiet bedroom at night
30 to 40dB(A)	Living room during the day
40 to 50dB(A)	Typical office
50 to 60dB(A)	Inside a car
60 to 70dB(A)	Typical high street
70 to 90dB(A)	Inside factory
100 to 110dB(A)	Burglar alarm at 1m away
110 to 130dB(A)	Jet aircraft on take off
140dB(A)	Threshold of Pain

The ear is less sensitive to some frequencies than to others. The A-weighting scale is used to approximate the frequency response of the ear. Levels weighted using this scale are commonly identified by the notation dB(A).

In accordance with logarithmic addition, combining two sources with equal noise levels would result in an increase of 3 dB(A) in the noise level from a single source.

A change of 3 dB(A) is generally regarded as the smallest change in broadband continuous noise which the human ear can detect (although in certain controlled circumstances a change of 1 dB(A) is just perceptible). Therefore, a 2 dB(A) increase would not normally be perceptible. A 10 dB(A) increase in noise represents a subjective doubling of loudness.

A noise impact on a community is deemed to occur when a new noise is introduced that is out of character with the area, or when a **significant increase above the pre-existing ambient noise level occurs**.

For levels of noise that vary with time, it is necessary to employ a statistical index that allows for this variation. These statistical indices are expressed as the sound level that is exceeded for a percentage of the time period of interest. In the UK, traffic noise is measured as the LA_{10} , the noise level exceeded for 10% of the measurement period.

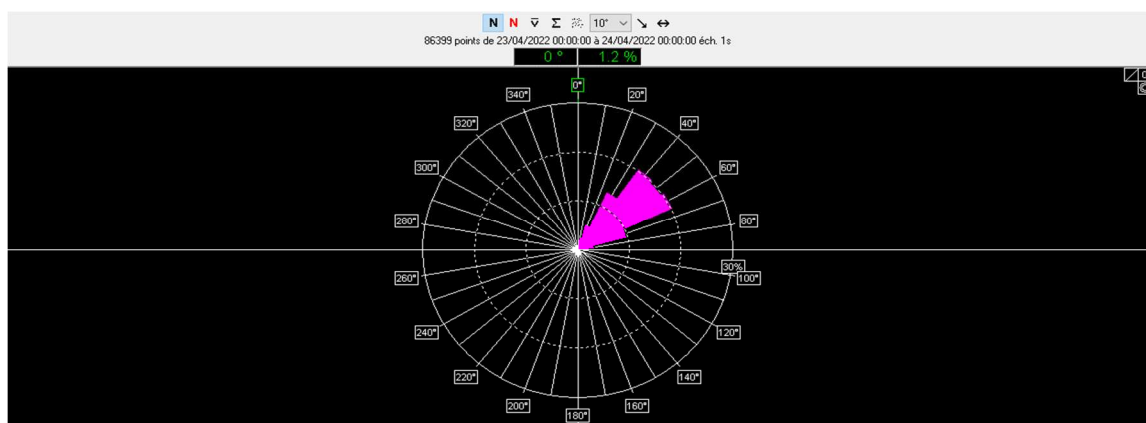
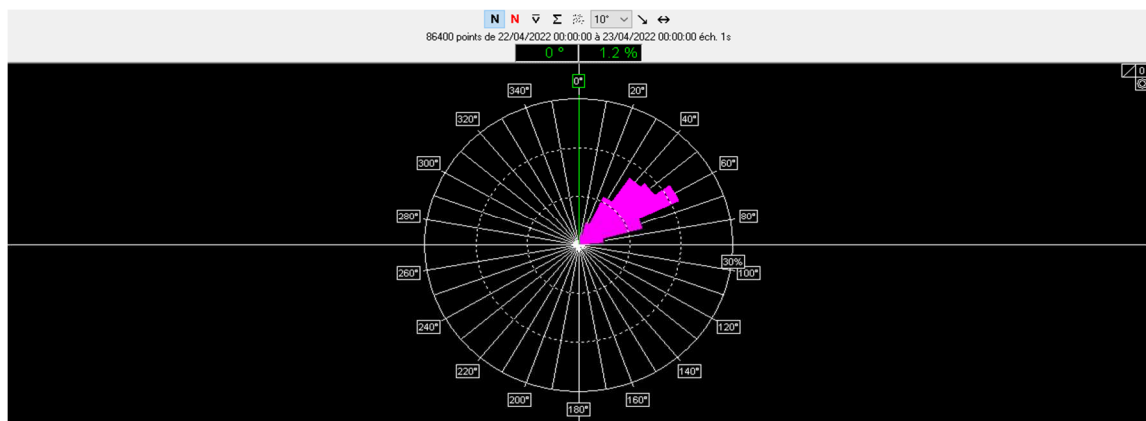
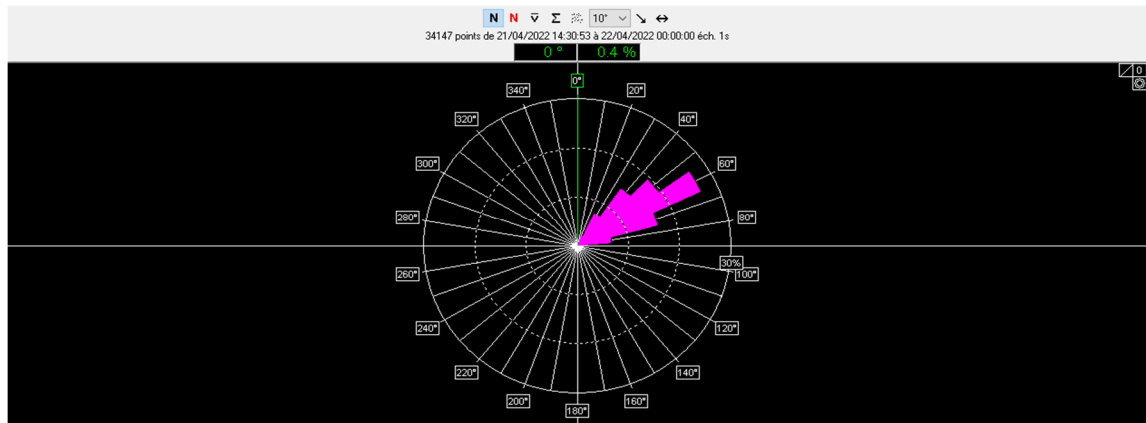
The LA_{90} is the level exceeded for 90% of the time and has been adopted to represent the background noise level in the absence of discrete events. An alternative way of assessing the time varying noise levels is to use the equivalent continuous sound level, LA_{eq} .

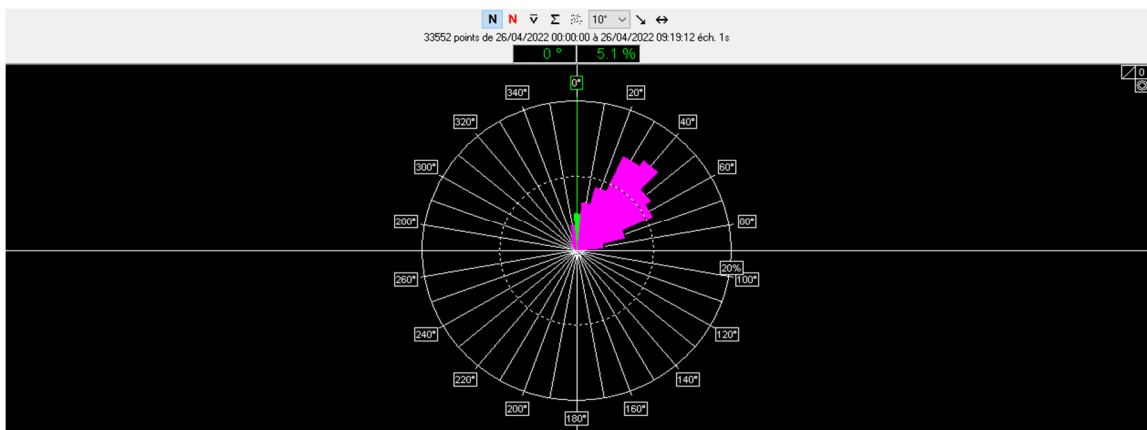
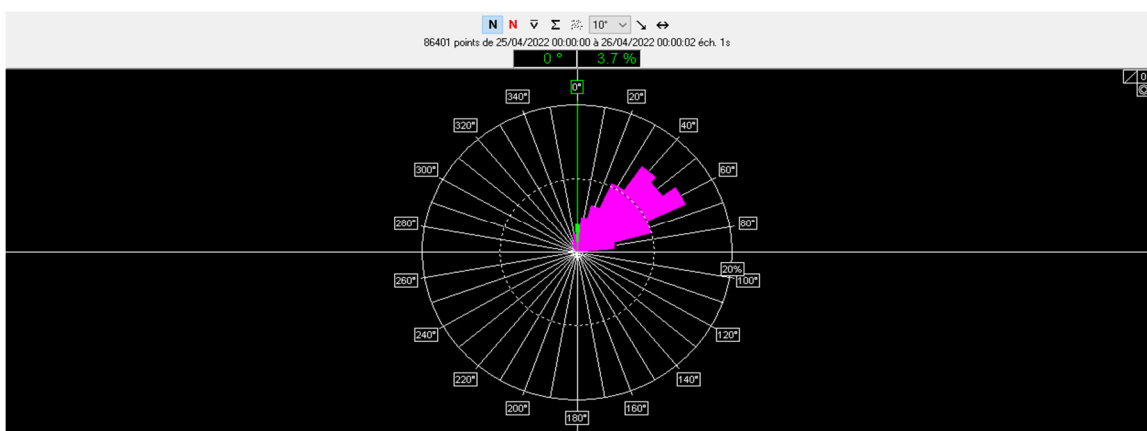
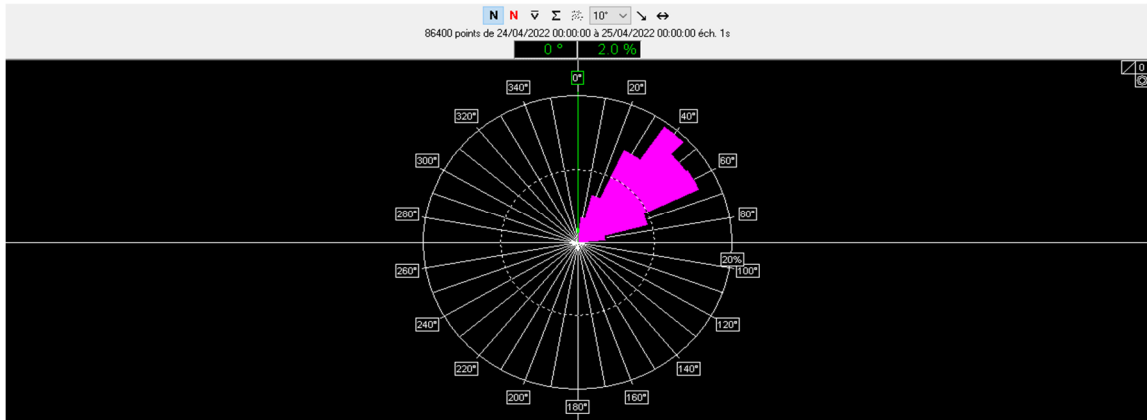
Example: when a receptor is predominantly affected by continuous flows of road traffic, a doubling or halving of the flows would result in a just perceptible change of 3 dB, while an increase of more than 25%, or a decrease of more than 20%, in traffic flows represent changes of 1 dB in traffic noise levels (assuming no alteration in the mix of traffic or flow speeds).

Appendix B – Measurement Results

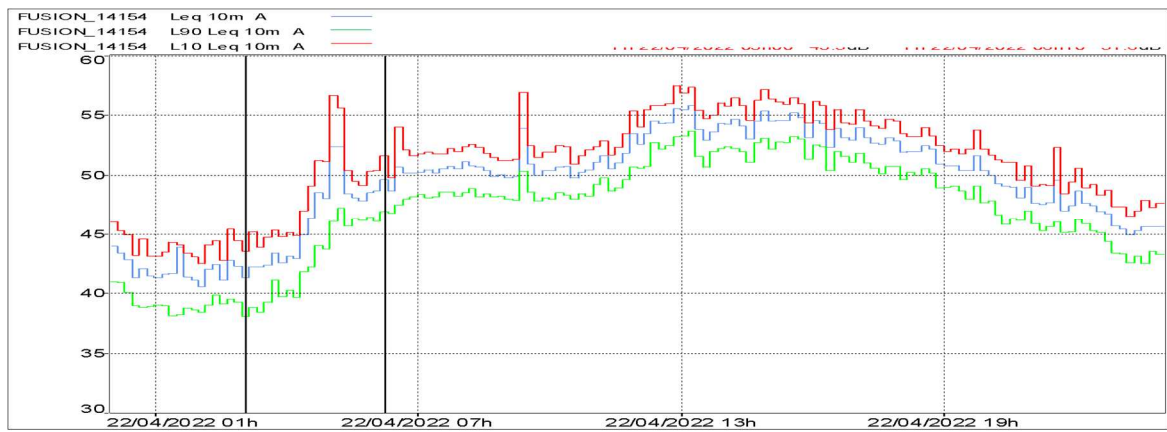
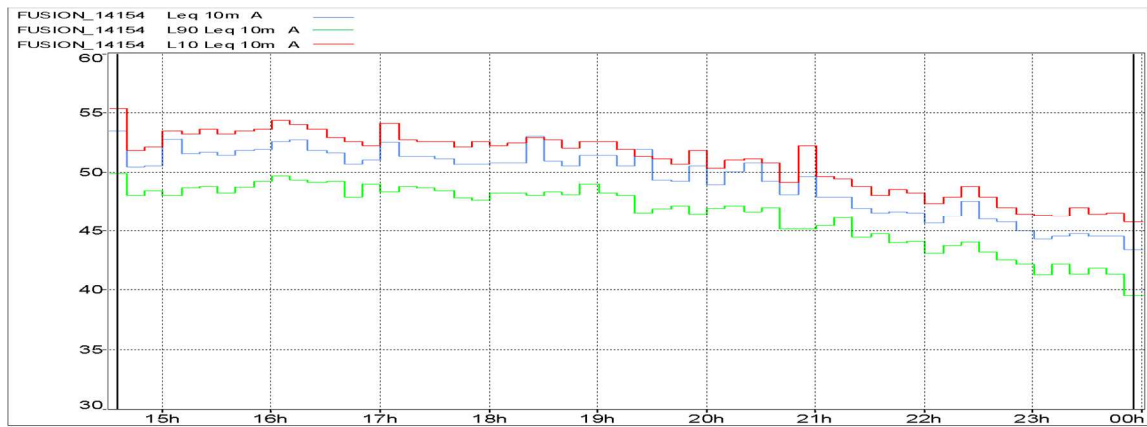
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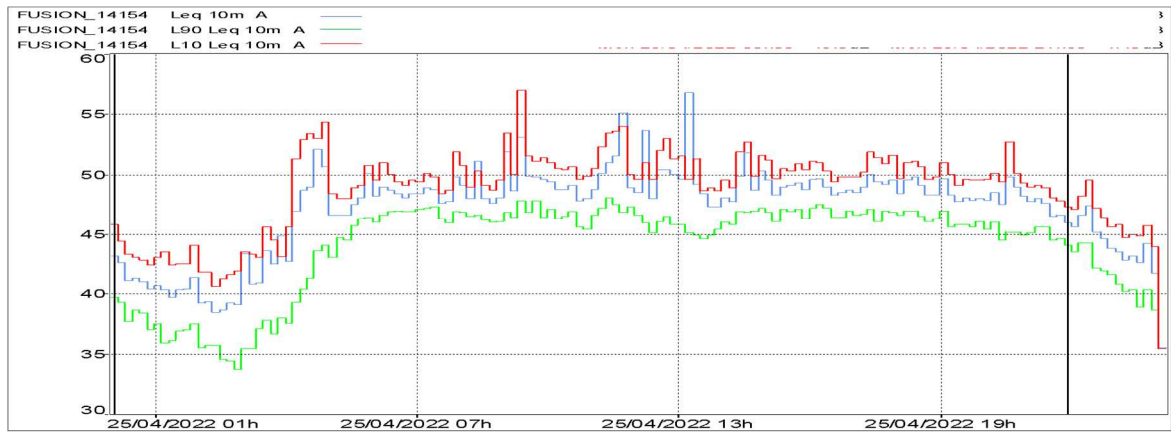
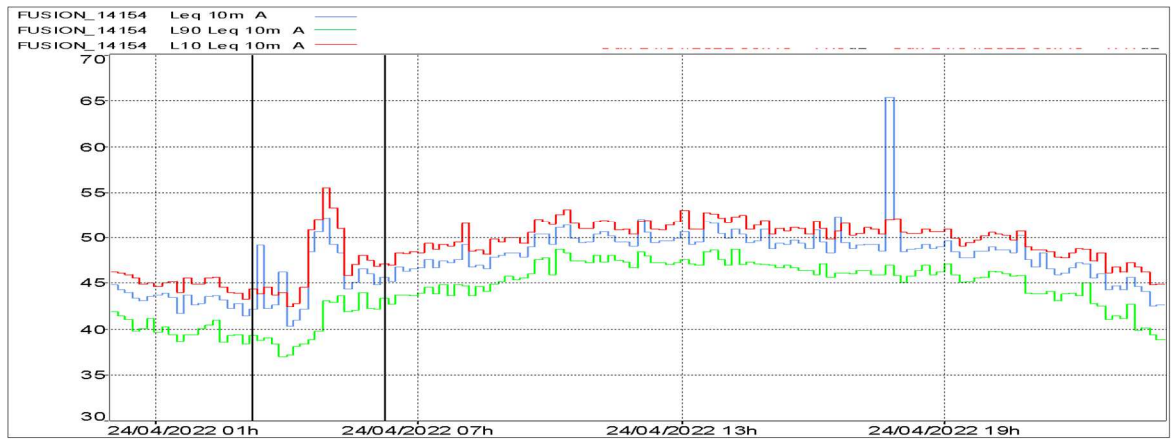
Wind direction charts per day





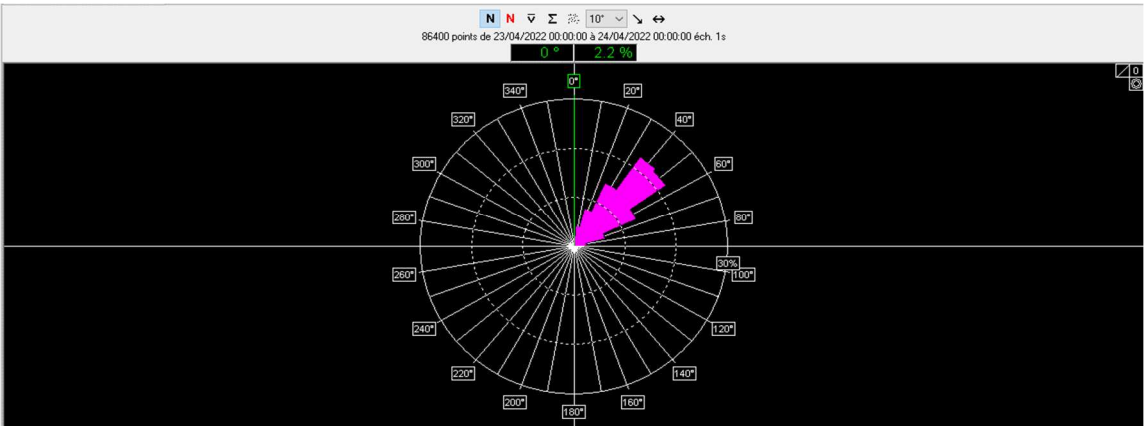
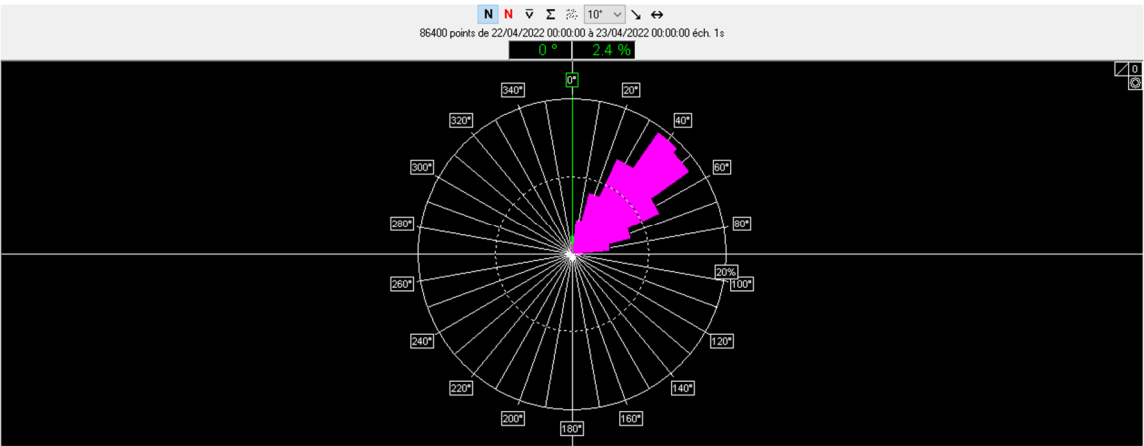
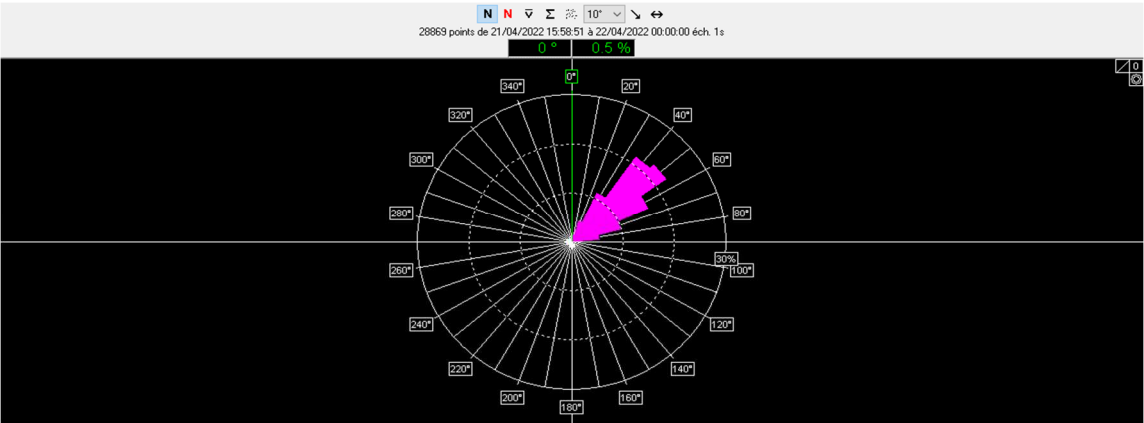
LA_{eq,10min}, LA_{90,10mins}, and LA_{10,10mins} Graphics per day

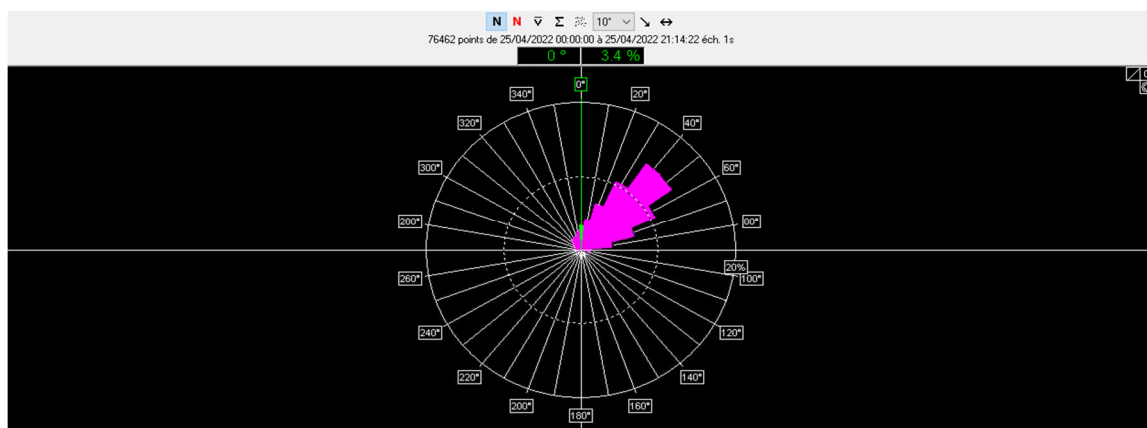
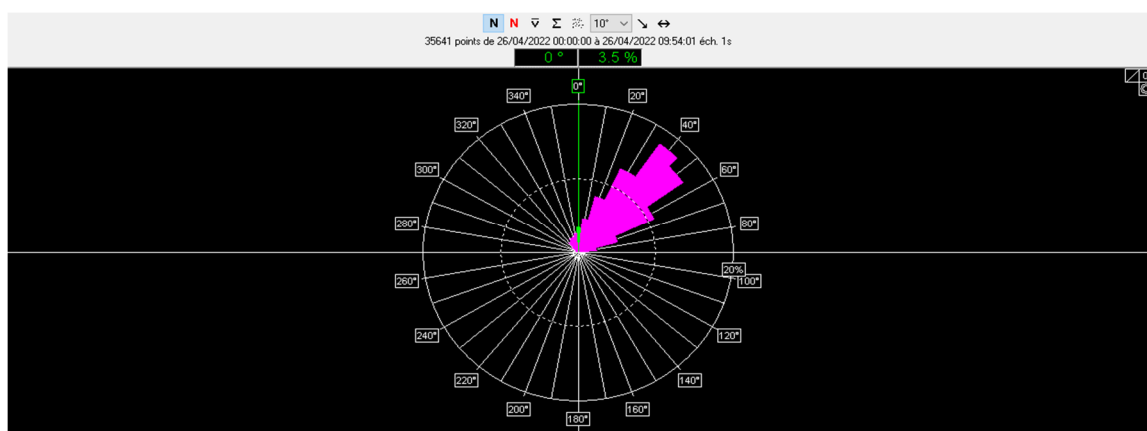
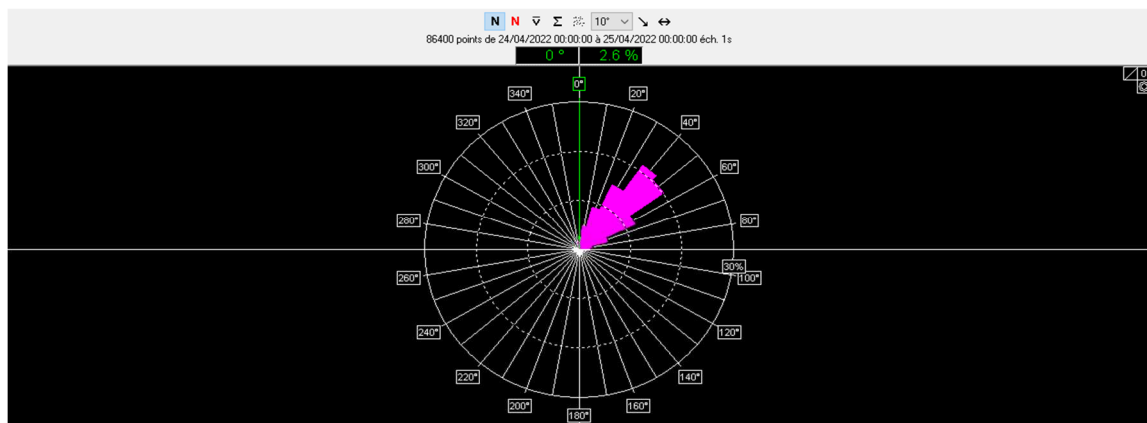




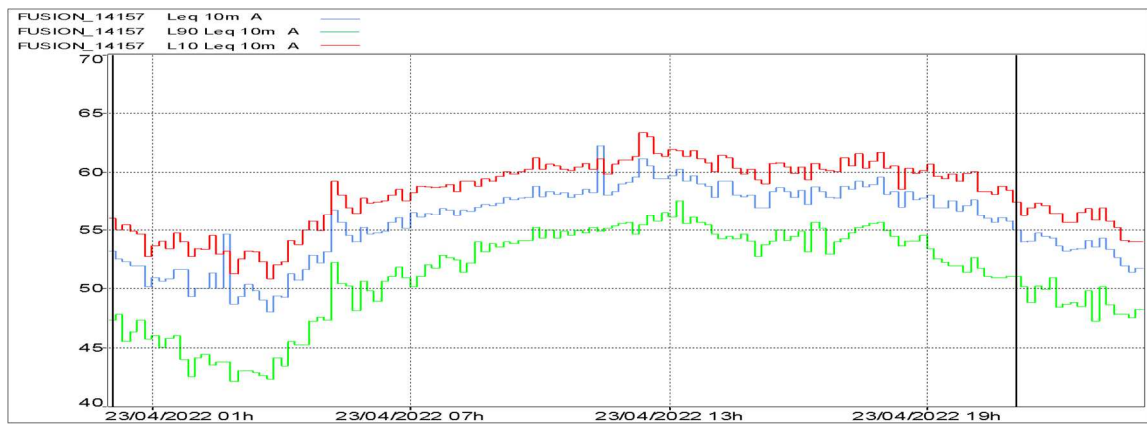
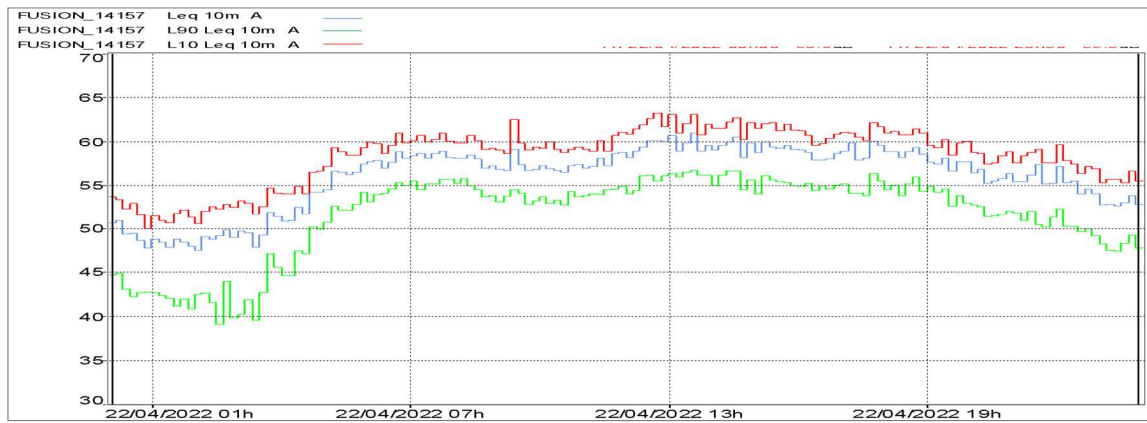
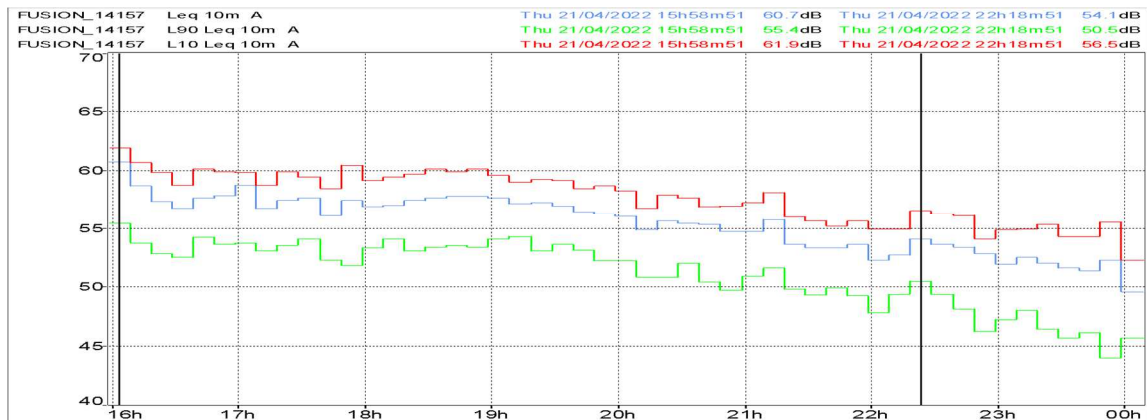
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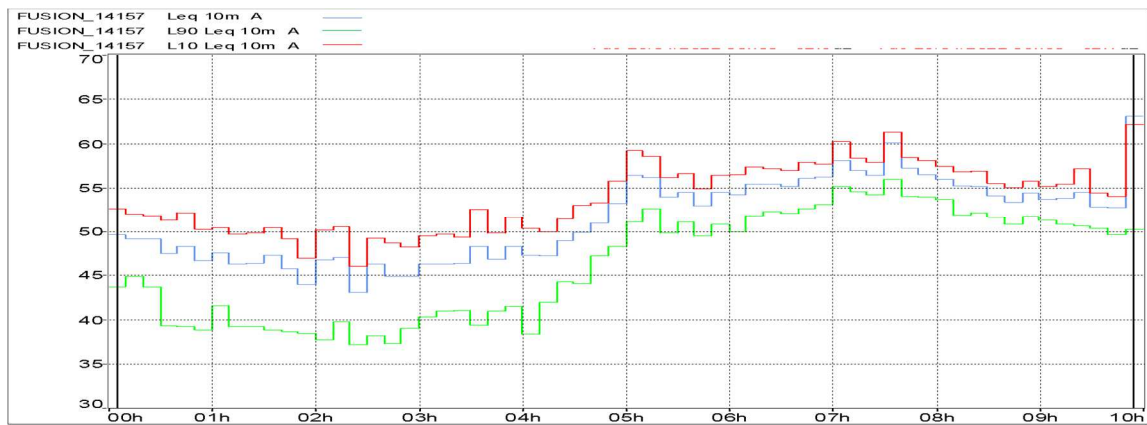
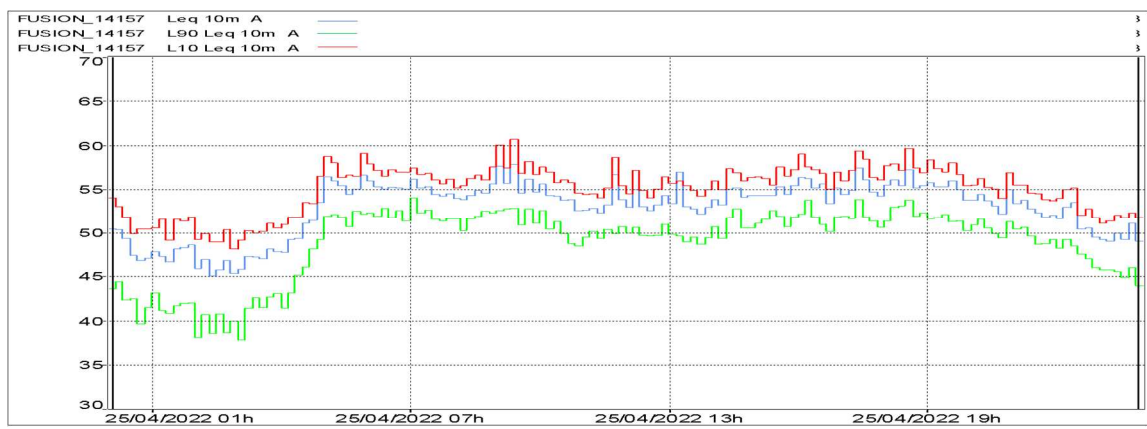
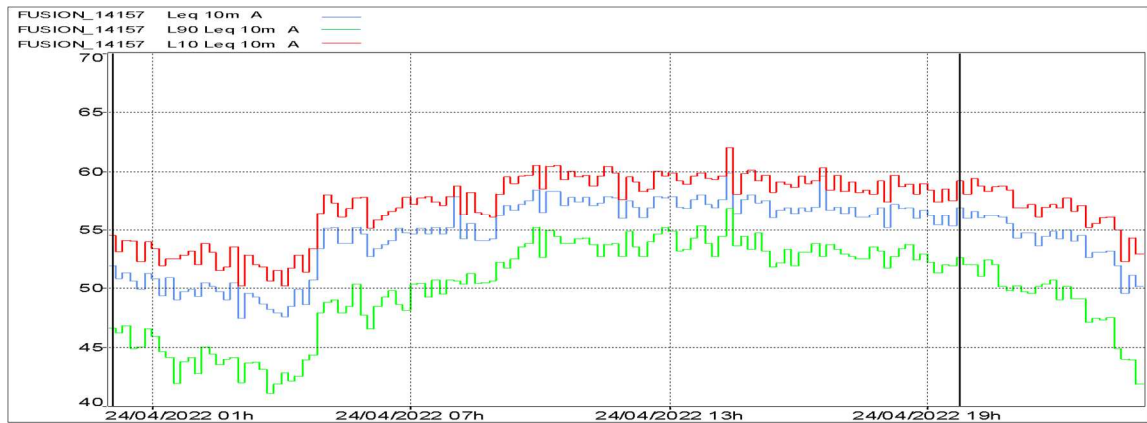
Wind direction charts per day



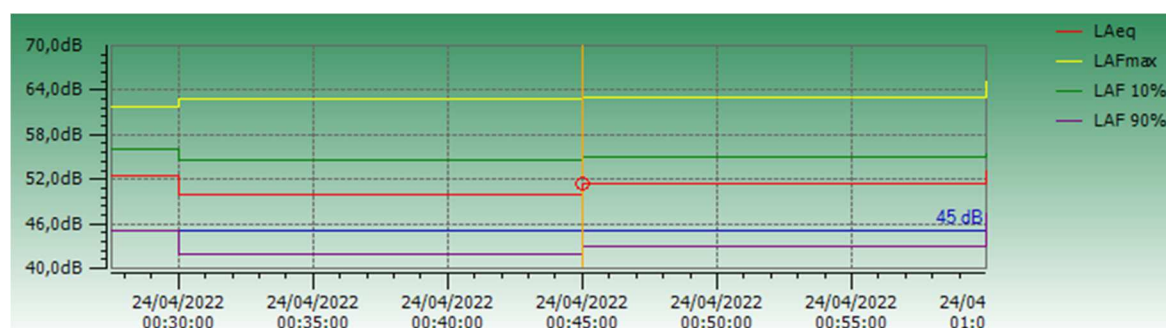
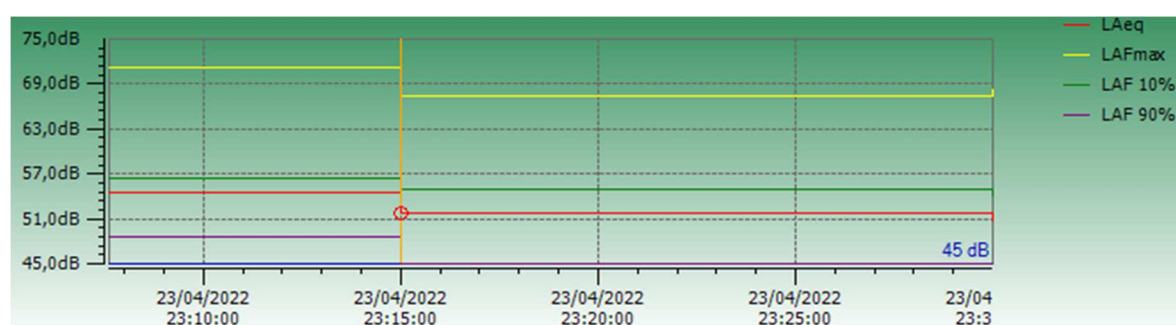
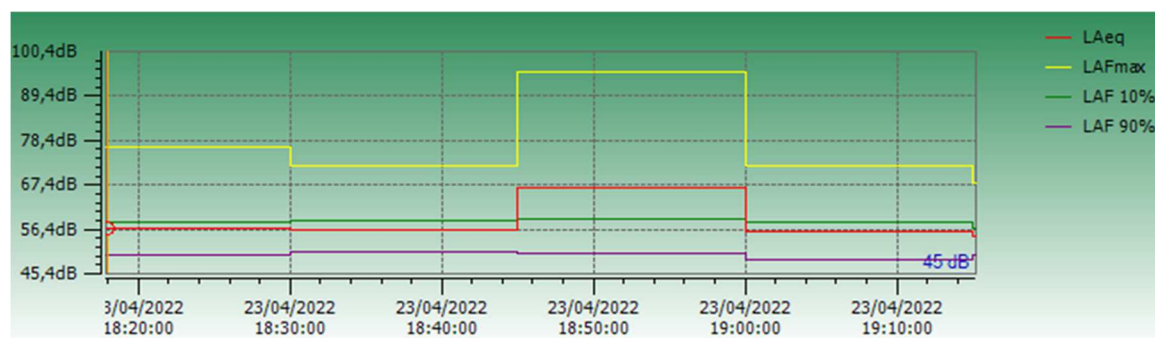


LA_{eq,10min}, LA_{90,10mins}, and LA_{10,10mins} Graphics per day





Attended Measurements at 5 Glapton Ln (Summary of the results)



Attended Measurements at 71 Rivergreen (Summary of the results)

