ANALYSIS OF URBAN NOISE IN DUBLIN USING LONG-TERM DATA FROM A PUBLICALLY ACCESSIBLE PERMANENT MONITORING NETWORK

Dermot Geraghty
Department of Mechanical & Manufacturing Engineering
Trinity College Dublin
Dublin 2
Ireland
Tel: +353 1 8961042
Fax: +353 1 6795554
Email: tgerghty@tcd.ie

Paul McDonald
Sonitus Systems Ltd.
The Tower
Trinity Technology and Enterprise Campus
Pearse Street
Dublin 2
Ireland
Tel: +353 1 2542560
Email: info@sonitussystems.com

Ivor Humphreys
Sonitus Systems Ltd.
The Tower
Trinity Technology and Enterprise Campus
Pearse Street
Dublin 2
Ireland
Tel: +353 1 2542560
Email: info@sonitussystems.com

Margaret O'Mahony*
Centre for Transport Research
Department of Civil, Structural & Environmental Engineering
Trinity College Dublin
Dublin 2
Ireland
Tel: + 353 1 8962084
Email: margaret.omahony@tcd.ie

*Corresponding author
Submission date: 01 August 2014
Number of Words: 4483 + (11*250) = 7233
Number of Figures: 4 Tables and 7 Figures

ABSTRACT

In 2002, the European Union issued a Directive relating to the assessment and management of environmental noise pollution, the aim of which was to put in place a European-wide system for identifying sources of environmental noise pollution, informing the public about relevant noise data and then taking the necessary steps to avoid, prevent or reduce noise exposure. Continuous monitoring allows local authorities to make comparisons with strategic noise maps, account for weather effects and seasonal changes in traffic volumes. The paper presents the development of a ruggedized environmental noise monitor designed for long term outdoor deployments. Other elements of the system include wireless data collection capability and a web-based user interface for use by clients. The paper charts the implementation of the system in Dublin and includes analysis of 5 minute interval data over a year from 10 sites. World Health Organisation and Irish local authority guidance levels are used to evaluate the environmental noise levels at the sites. One of the novel aspects about the Dublin monitoring network is that it is being used to monitor one of the first urban "quiet areas" to be designated in Europe. The paper concludes by showing the significant potential the network has in identifying sites requiring action in terms of reducing noise exposure to citizens and providing information to the public about their exposure to environmental noise.

INTRODUCTION

In 2002, the European Union (EU) issued a Directive (2002/49/EC) *(1)* relating to the assessment and management of environmental noise pollution. The Directive's main aim is to put in place a European-wide system for identifying sources of environmental noise pollution, informing the public about relevant noise data and then taking the necessary steps to avoid, prevent or reduce noise exposure. The Directive aims to monitor environmental noise problems by requiring competent authorities in Member States to generate strategic noise maps for major roads, railways, airports and agglomerations, using the harmonised noise indicators L_{DEN} (day-evening-night average sound level) and L_{NIGHT} (night time average sound level). These maps are to be used as a means of presenting environmental noise data, as a source of information for the public and as an aid in the preparation of noise action plans. For an example of a recent noise action plan see *(2).*

All member states of the EU are required to develop strategic noise maps. The first phase of these noise maps was delivered in 2007 and the second phase was delivered in June 2012. Updated versions of the strategic noise maps are due every five years thereafter. Strategic noise maps present environmental noise level data in terms of a relevant noise indicator. Their purpose is to allow authorities to identify areas where a noise limit value may have been exceeded, estimate the number of people potentially exposed to environmental noise and evaluate the contribution of various noise sources to the overall noise situation *(2).* One of the underlying themes throughout the Directive is the dissemination of noise data to the general public using channels and media that are both suitable and effective. The Directive instructs that the public be made aware of any noise assessment data, be consulted during the formulation of action plans and informed of any decisions taken.

The noise measurement network described here is owned and maintained by Dublin City Council who are responsible for noise monitoring and amelioration in the city and for provision of information on noise levels to the public. Continuous monitoring allows the council to make reliable comparisons with strategic noise maps, account for weather effects and seasonal changes in traffic volumes. Following a round of noise mapping in 2012, and the Noise Action Plan produced on the foot of this, eight locations in the city were designated as

'Urban Quiet Areas' in August 2013 *(3).* Daytime and night time noise limits of 55 dBA and 45 dBA respectively have been established for these 'quiet' areas. Clearly, continuous monitoring is needed to verify that these noise targets are not exceeded and to alert the council to significant changes in the noise environment.

One of the major themes of the Environmental Noise Directive is the sharing of information with the public. Noise maps, action plans and results of policies should be shared through the most appropriate and accessible means. In addition to data collection, the measurement network also makes all readings available to the public through a web based interface www.dublincitynoise.com as shown in Figure 1 *(4).* The data are also uploaded by the European Environment Agency NoiseWatch *(5).*

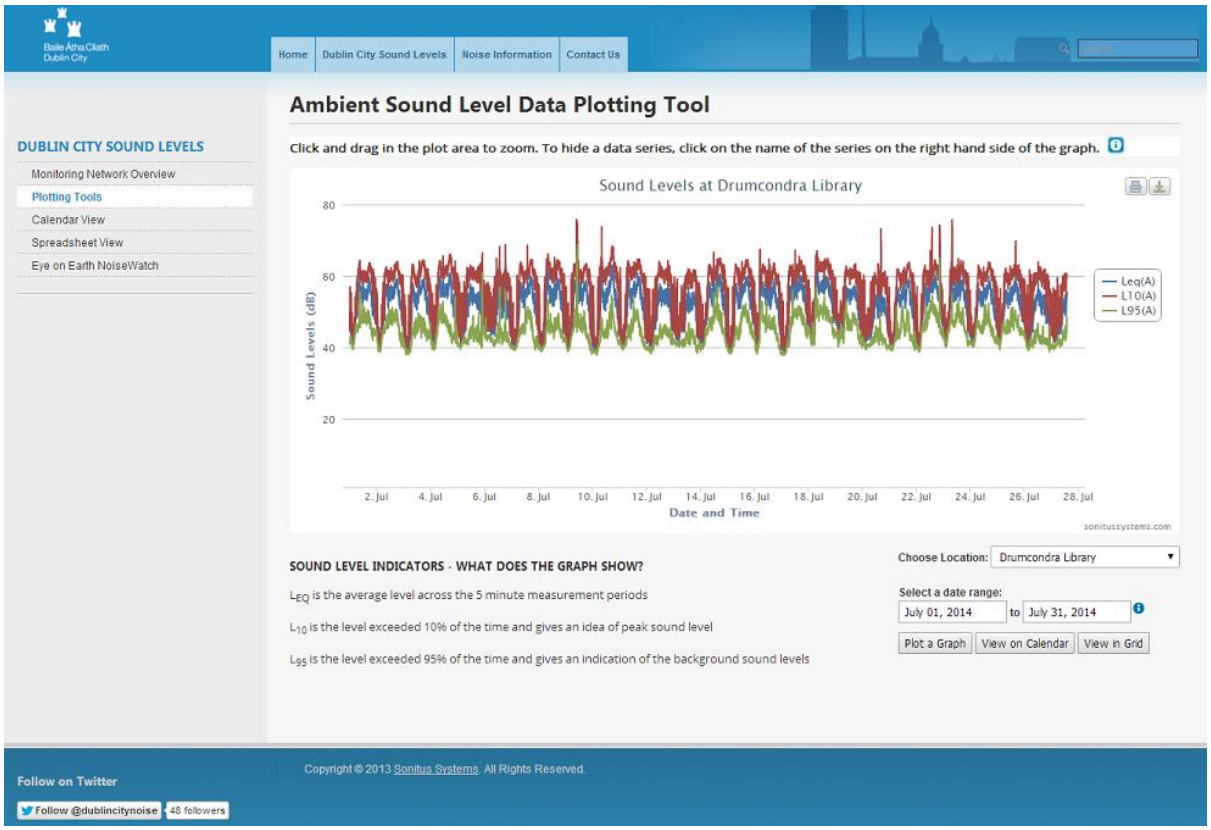

FIGURE 1. Dublin city noise network web-based interface *(4)*

BACKGROUND

There are very good reasons for monitoring environmental noise. It's not just simply a matter of annoyance or inconvenience. Epidemiological studies suggest that long-term noise exposure can lead to cardiovascular and other diseases *(6,7).* Other research notes that exposure to traffic noise may be associated with psychological and physiological effects including sleep disturbance, stress reactions, hypertension and diabetes *(8, 9, 10, 7).* Frei et al *(11)* examined the effect of nocturnal road traffic noise on objective and subjective sleep quality where they found that sleep efficiency is impacted upon by exposure to road traffic noise.

Modelling of traffic noise has been used in the analysis of mitigation measures during road construction *(12, 13).* Other work focuses on identifying variables that result in the highest noise incidence, for example, Tang et al *(14)* uses models to look at the influences of urban

forms on traffic-induced noise and air pollution. Ramirez et al *(15)* modelled urban traffic noise with stochastic and deterministic traffic models.

Other research focuses predominantly on noise measurement. Guoqing et al *(16)* examined the relationship between urban combined traffic noise and annoyance in Dalian and found that the percentage of highly annoyed people was higher when road and rail noise was combined compared with only one dominant source. Zuo et al *(17)* found that noise exposure was ubiquitous across Toronto and that noise variability was mostly explained by spatial characteristics.

While noise prediction and short duration 'on the spot' measurements are useful the ideal situation is to have a dense network of permanent noise monitoring stations recording levels on a 24/7 basis. Data from measurement stations can be used to check noise mapping predictions and tune the predictions. Also, having actual noise measurements as well as predictions is a significant confidence booster for those authorities charged with noise monitoring and mitigation responsibilities.

Installation of the Dublin network began in 2008 on a pilot basis using prototype equipment and since then the network has been expanded annually, the only constraint being budgetary. Other noise monitoring networks are in place in a number of cities in Europe including, Gdansk in Poland *(18),* Lille in France *(19)* and Pisa, Italy.

DESCRIPTION OF INSTRUMENTATION AND INSTALLATIONS

Instrumentation

The environmental noise monitor used in this study is the Sonitus Systems EM2010 *(4)* (see Figure 2). This unit is a ruggedized environmental noise monitor designed for long term outdoor deployments. It operates on a 24/7 basis and reports noise statistics at user programmed intervals via a global system for mobile communication (GSM) link. Each unit is fitted with a Class 2 environmental microphone and noise measurements are compliant with IEC61672 *(20)* and the unit has been certified by the National Standards Authority of Ireland (NSAI). The user can choose from a range of noise statistics to record. In this deployment the following A and C weighted statistics were calculated and recorded: L_{EQ}, L_{05}, L_{10}, L_{50}, L_{90}, and L_{95}. L_{EQ} values were calculated for 5 minute periods and the dynamic range of the system is 33 dBA to 121 dBA.

FIGURE 2. A Sonitus Systems EM2010 environmental noise monitoring unit

In total 29 noise monitoring units have been deployed in Dublin since 2008 with some units in place for up to 5 years. (We have chosen 10 of these sites for detailed analysis in this paper). The deployment has proved extremely reliable with all units achieving a very high level of coverage; based on a 5 minute measurement period a unit should record 105,210 readings per annum. All of the units have achieved in excess of 95% of this perfect 'score', with most units recording data more than 97% of the time. Missing data points are few and have been attributed to brief power outages and down time for calibration checks. The percentages for each unit are presented in Table 1 below.

TABLE 1 Reliability of monitors

Site Name	Site Number	% 24 hour data	% Day time data (7:00-22:59)	% Night time data (23:00-06:59)
Drumcondra	**Site 1**	98.8	99.1	98.3
Ballyfermot	**Site 2**	98.4	98.8	97.6
Ballymun	**Site 3**	97.4	97.6	97.0
Dublin City Council Rowing Club	**Site 4**	95.8	96.1	95.3
Walkinstown	**Site 5**	98.5	98.8	97.9
Woodstock Gardens	**Site 6**	97.7	97.9	97.3
Navan Rd	**Site 7**	96.4	96.8	95.4
Irishtown Stadium	**Site 8**	93.9	94.2	93.3
Chancery Park	**Site 9**	98.8	99.1	98.3
Blessington St Basin	**Site 10**	96.7	97.0	96.1

Choice of Measurement Sites

The primary factors in choosing the sites were a) location of public amenities such as libraries, b) the presence of a potential noise 'hot spot' indicated by a strategic noise map c) representative locations for major noise sources and d) an area designated as an Urban Quiet Area. It should be noted that sites are selected so that, in so far as is possible, no single dominant sound source, such as major roads, road junctions, industrial sources etc. have a disproportionate influence on the outdoor ambient sound levels being measured. This comment was included in the Dublin plan. The sites and the rationale for choosing them are summarised in Table 2 along with the distance from each site to the closest major noise source.

TABLE 2 The rationale behind sound measurement site selection

Site	Rationale for choosing Site	Distance to nearest major noise source (m (yd))
Drumcondra	Library - opposite public park (Griffith) and close to a national route (N1)	250 (273.4)
Ballyfermot	Close to a busy route into the city with a high volume of slower moving traffic	50 (54.7)
Ballymun	Library, next to a school and recreational ground, close to a busy artery	100 (109.4)
Dublin City Council Rowing Club	Recreational area of natural beauty, adjacent to National Park and close to busy artery	100 (109.4)
Walkinstown	Close to busy route in residential area	200 (218.7)
Woodstock Gardens	Retirement village in highly residential area, with high volumes of slow traffic	100 (109.4)
Navan Rd	Next to National Park on busy national route into city (N3)	50 (54.7)
Irishtown Stadium	Recreational sports ground close to busy freight route (port traffic)	300 (328)
Chancery Pk	Adjacent to the Luas (Tram) Line	50 (54.7) to Luas (LRT line) and 250 (273.4) to busy road
Blessington St Basin	Designated an 'Urban Quiet Area', one of 8 in Dublin in 2013 *(3)*	100 (109.4)

The map of their locations is presented in Figure 3 (the data from the numbered sites are those included for this paper).

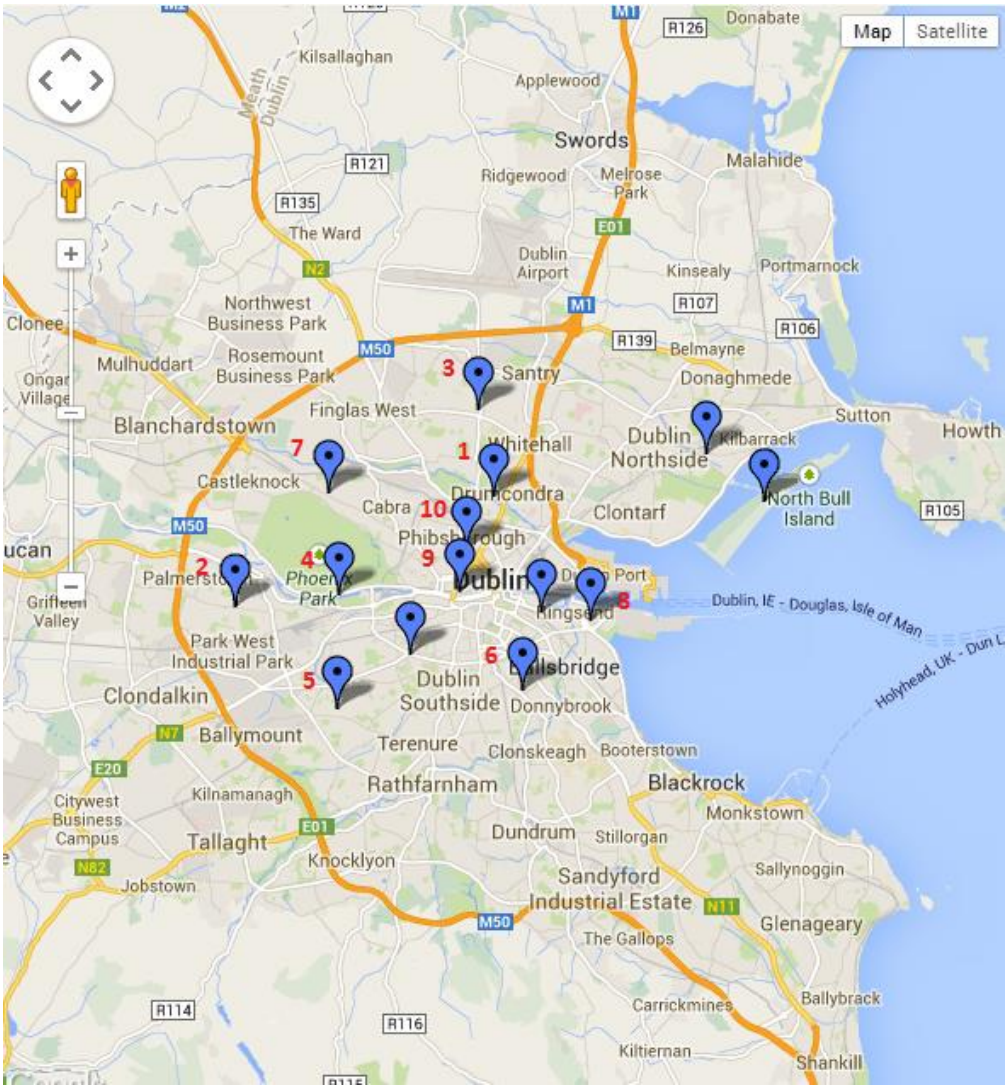

FIGURE 3 Map of locations of sound monitoring sites in Dublin

RESULTS

At present there is no existing legislation that limits environmental noise levels to a particular value. Several difficulties arise when attempting to choose a reasonable value for noise level limits, mainly due to the subjective nature of noise exposure and annoyance. The effects of noise exposure are highly dependent on the perception of the exposed person and the effectiveness of noise reduction can often be dependent as much on relative changes as on absolute levels. Attempting to apply the same limit value to a city centre park and rural country side may be inappropriate, despite the fact that both can be perceived as tranquil areas relative to the surroundings.

The Dublin City Council Noise Action Plan Oct 2008-Nov2013 *(21)* proposes that areas with undesirable high sound levels are areas with a night time sound level, L_{NIGHT}, greater

than 55 dBA and an L_{DEN} level greater than 70 dBA. Areas with desirably low sound levels are defined as areas with an L_{NIGHT} less than 50 dBA and/or a L_{DEN} level of 55 dBA.

L_{DEN} is the derived statistic calculated as follows

$$L_{DEN} = 10 \log \frac{1}{24}\left(12 * 10^{\frac{L_{DAY}}{10}} + 4 * 10^{\frac{L_{EVENING}+5}{10}} + 8 * 10^{\frac{L_{NIGHT}+10}{10}}\right)$$

where L_{DAY} is the A-weighted long-term average sound level measured between 07.00 and 19.00, $L_{EVENING}$ is the A-weighted long term-average sound level measured between 19.00 and 23.00 and L_{NIGHT} is the A-weighted long-term average sound level measured between 23.00 and 07.00 *(1)*

These values can be seen as indicative criteria in the decision making process. Combined with the graphical results of noise mapping, consideration of the number of people exposed and the type of property, the guidelines provide a useful framework for assessing noise impact. The average day, evening and night values are determined over all the respective periods of a year, making the L_{DEN} a yearly average. A 5 dB weighting is added to the evening noise value and a 10 dB weighting added to the night time level. This is to account for the fact that the same noise level may be more annoying at different times of the day.

L_{DEN} and L_{NIGHT} for the 10 sites in Dublin using the year's data are presented in Table 3. In the context of determining if a site is experiencing undesirably high sound levels, none of the sites exceed the level of L_{DEN} of 70 dBA but the two sites located close to major arterial roads exceed the L_{NIGHT} level; Site 3 and Site 9 have levels of 57.2 and 57.8 dBA respectively. When the sites were examined to see if they could be considered as areas with desirably low sound levels, only Site 6 has a L_{DEN} lower than 55 dBA and an L_{NIGHT} less than 50 dBA. Site 10 has a level marginally below the L_{NIGHT} level at 49.9 dBA with Sites 1 and 5 marginally above.

TABLE 3 L_{DEN} and L_{NIGHT} for the 10 sites

	L_{DEN}(dBA)	L_{NIGHT} (dBA)
Site 1	59.2	50.1
Site 2	61.3	53.1
Site 3	66.5	57.2
Site 4	60.6	52.6
Site 5	59.0	50.8
Site 6	54.2	46.7
Site 7	60.3	52.9
Site 8	61.2	54.4
Site 9	65.6	57.8
Site 10	57.8	49.9

To explore the degree of variation between sites and between day, evening and night within each site, a boxplot of the year's measurements in terms of Leq dBA are presented in Figure 4. The designations of D, E and N refer to daytime, evening and night time as defined above. The interquartile range is relatively small for all sites and most are showing an asymmetrical distribution towards the higher values. As might be expected, the trend of higher levels during the day followed by evening and then night are repeated for all sites and the two sites nearest main arterial roads can be seen here again to have the highest values overall.

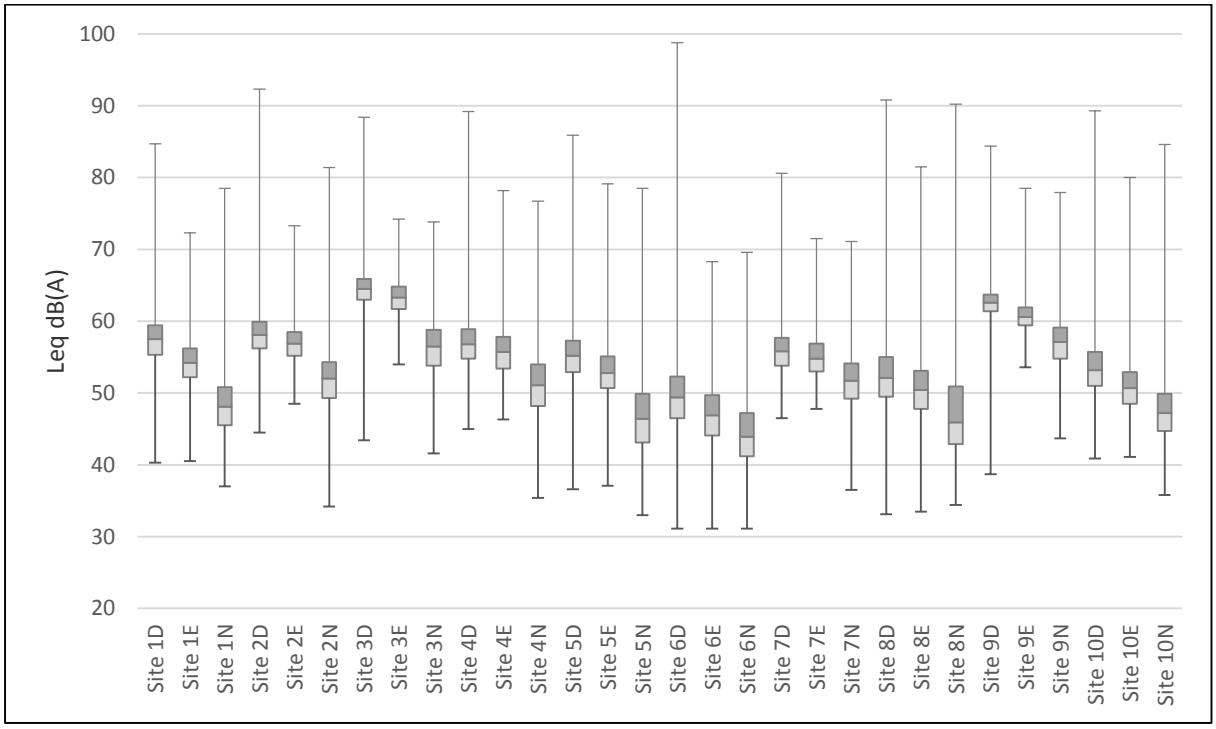

FIGURE 4. Box plot of daytime, evening and night time sound levels.

The guideline values recommended by the World Health Organisation *(22)* were also used to evaluate the sound measurements. In particular, the level of 55 Leq dBA during daytime and evening was selected because it represents the level at which serious annoyance occurs. The Leq dBA level of 70 dBA over 24 hours was selected because the guideline indicates potential hearing impairment above those levels. The level of 45dB Leq dBA was selected for the night time period from 23:00 – 7:00. The numbers of data measurements used for each time period examined are presented in Table 4.

TABLE 4 Data count for each time period

Site	24 hour data	Day time data (7:00-22:59)	Night time data (23:00-06:59)
Site 1	103,877	69,445	34,432
Site 2	103,463	69,268	34,195
Site 3	102,403	68,421	33,982
Site 4	100,765	67,360	33,405
Site 5	103,578	69,290	34,288
Site 6	102,720	68,628	34,092
Site 7	101,317	67,870	33,447
Site 8	98,700	66,003	32,697
Site 9	103,838	69,398	34,440
Site 10	101,656	67,998	33,660

Note: Site 1 = Drumcondra, Site 2 = Ballyfermot, Site 3 = Ballymun, Site 4 = DCC Rowing Club, Site 5 = Walkinstown, Site 6 = Woodstock Gdns, Site 7 = Navan Rd. Site 8 = Irishtown, Site 9 = Chancery Pk, Site 10 = Blessington St Basin

For the analysis of Leq dBA levels, the data were sorted and frequencies were analysed for each 5 dBA bin. The percentage of time different noise levels are exceeded are presented in Figure 5. Of note is the degree of difference between the sites. Only Sites 8 and 10 show similarity. Figure 5 can also be used to determine what proportion of the time the noise levels exceed the WHO guidelines *(22)* of the 55 dBA level. Site 6 shows levels above that for only 6% of the time compared with levels at Site 9 exceeding it for 91% of the time. The remainder of the sites show exceedance for anything from 17% to 88% of the time.

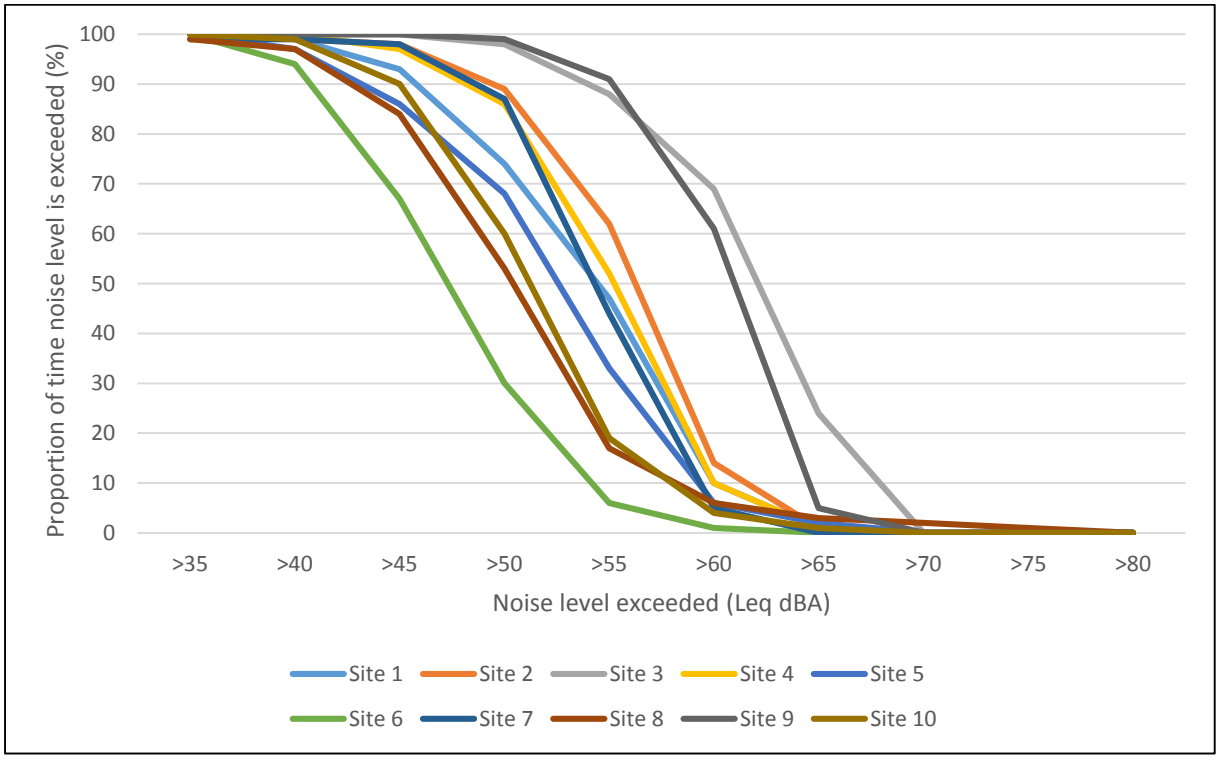

FIGURE 5 Proportion of time noise levels are exceeded

Having examined the noise distributions using all data, the data were then split between day time and night time. Day time was taken to be from 7:00 – 22:59 and night time from 23:00 - 06:59. The proportion of time Leq dBA noise levels were exceeded is presented in Figure 6. As might be expected from the earlier analysis, Sites 9 and 3 are again experiencing high noise levels with Site 6 having the lowest noise levels.

When exceedance of the WHO guidance level of 55 dBA is examined, it can be seen that Sites 9 and 3 exceed this level 100% of the time during day time hours, Site 2 exceeds it for 84% of the time, Sites 4 and 1 exceed it for 68-69% of the time and the others exceed it from 57% down to 7% of the time; Site 6 showing the lowest level.

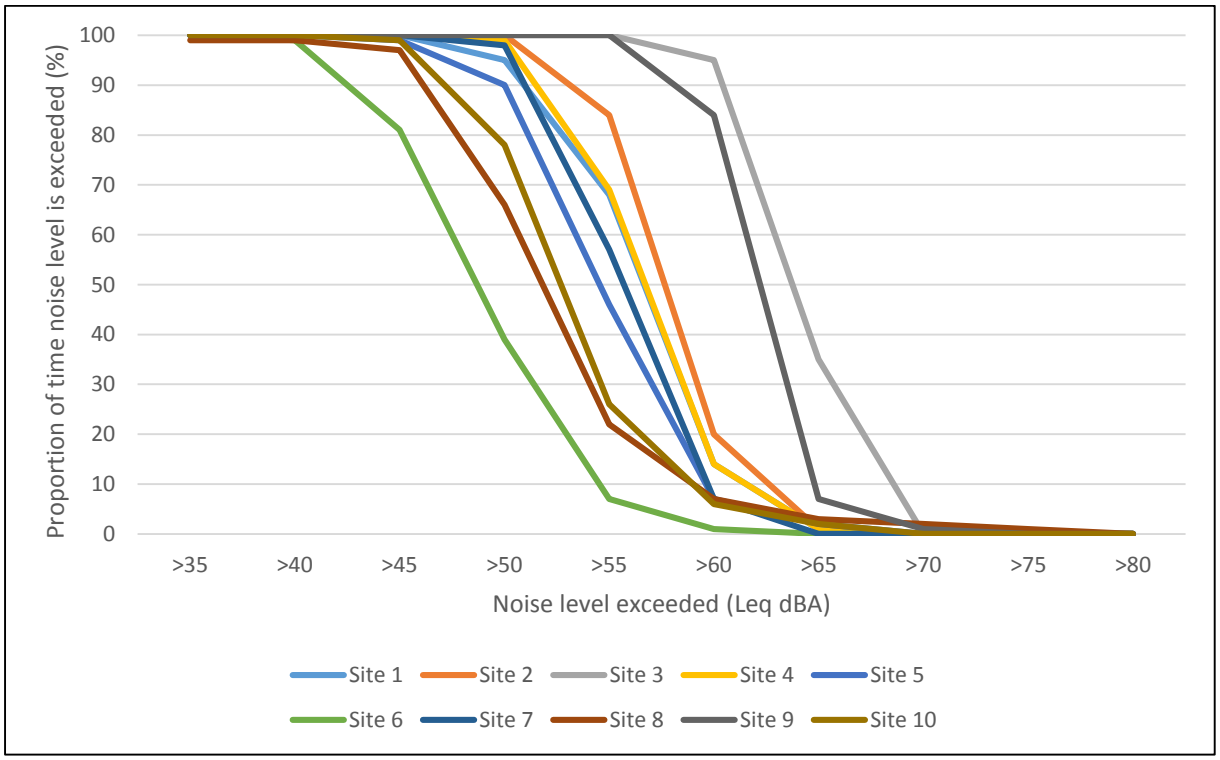

FIGURE 6. Proportion of time noise levels are exceeded during the day

Similar distributions are examined for the night time data in Figure 7. Of note is the relatively high proportion of the night most of the sites are experiencing levels of 50 dBA and higher. Six of the sites exceed the 45 dBA WHO night noise level over 92% of the time and the quietest site, Site 6, exceeds it 40% of the time.

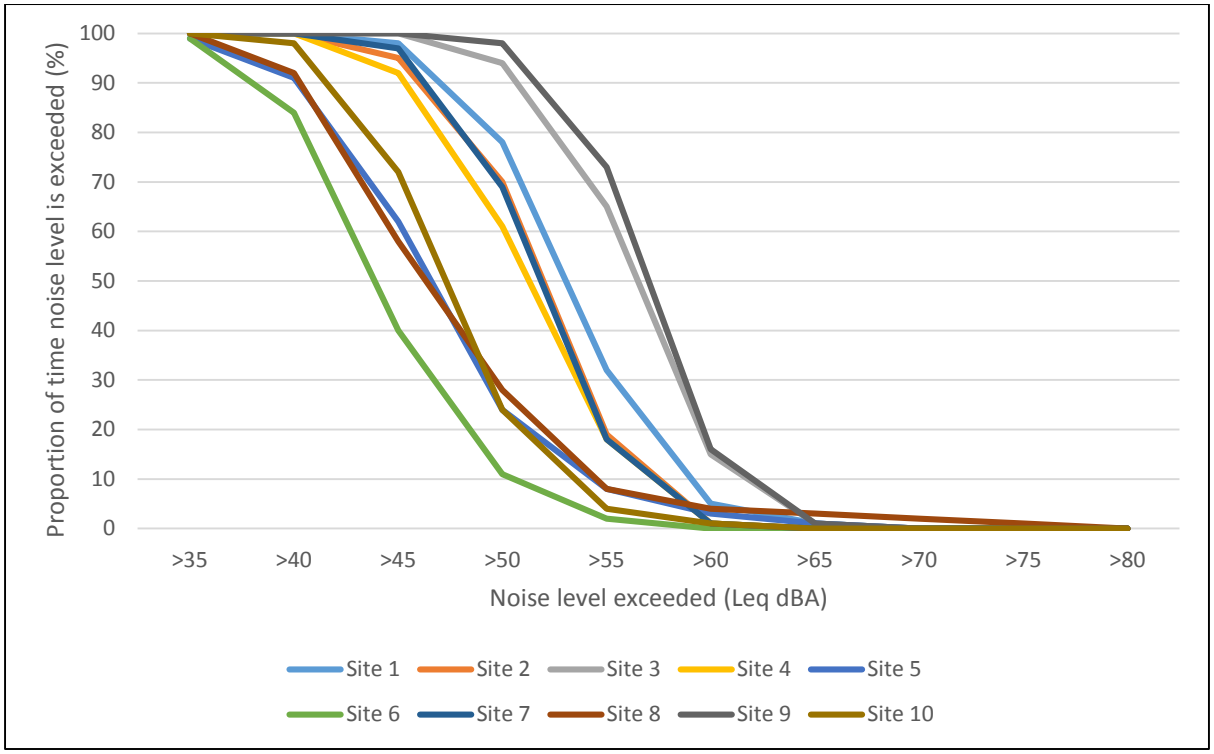

FIGURE 7 Proportion of time noise levels are exceeded during the night

DISCUSSION AND CONCLUSIONS

The analysis demonstrates the usefulness of long-term monitoring of noise in urban areas across different geographical locations but also across sites with different features. If measurement sites can be taken as representative of major noise sources then residential developments in similar locations, close to sources of noise are potentially exposed to noise levels above WHO guidelines *(22)*. Availability of data over a long time frame allows local authorities to identify problems, determine effects of seasonal inputs and develop strategies to reduce noise exposure. Public availability of measurement information provides educational and informative tools for the public, aids local authorities in making noise a public issue i.e. community engagement.

The results give an indication of the variability in noise levels that can be present at different sites across a city. Sites near dual-carriageways or busy arterials such as Sites 3 and 9 demonstrate, as expected, significantly high noise levels throughout the day and night. Other sites, such as Site 6, while relatively close to a street, have lower noise levels reflecting lower numbers of lanes on the nearby road but also slower moving traffic. This site has recently joined Site 10 as a 'designated quiet area'.

The primary shortfall of the predictive noise mapping technique is the large amount of data inputs that are needed. In a dense urban area these are often estimated, using average speed limits and traffic volumes. This tends to give predictions that are uniform across numerous similar areas where accurate data is not available. The analysis shows that in reality there is significant variance between areas which might otherwise have been classified as similar locations. Using the long term measurement network provides both a means for refining the noise mapping model and more accurately assessing the noise exposure levels in the area.

In conclusion, the network has proven to be very reliable with all units operating for more than 95% of the time. There are short outages for calibration checks and maintenance which are unavoidable. Consequently the data set is extensive and there are no 'deaf' periods, leading to a high level of confidence in the measurements. While only 10 units have been chosen for analysis in this paper the performance is representative of the entire network.

In terms of the results from the data analysis, all sites had noise levels below the 70 dBA level WHO *(22)* guidance level but meeting the guideline of 55 dBA would appear to be more challenging in urban areas. The analysis shows that the percentage of time this level is exceeded ranges between 6% and 91% with most of the sites in the range 17% to 88% of the time. In relation to the examination of L_{DEN} and L_{NIGHT} none of the sites exceed the level of L_{DEN} of 70 dBA but the two sites located close to major arterial roads exceed the L_{NIGHT} level.

Part of the novelty of the network is the high level of automation in the capture, reporting and analysis of data. Like many local authorities the City Council are restricted in terms of the budget and manpower they can dedicate to environmental assessments. By deploying an autonomous network specifically designed for long term unattended operation, the City Council can develop detailed noise models in key areas without the need for large investment of resources. This in turn allows for more targeted actions when managing noise – such as protecting quiet areas or assessing exposure in large residential areas.

In the period 2008 - 2013 Dublin City Council, on foot of data from the noise monitoring network and their noise mapping actions, has carried out a number of measures to reduce noise in the city. The major actions were:

a) Designation of an inner cordon within the city from which Heavy Goods Vehicles (HGV) are prohibited between 0700 and 1900. This has largely eliminated HGV traffic in the city during this time period
b) Instigation of traffic calming measures by reducing maximum speeds and hence noise levels
c) Increased focus on parking controls which in turn reduced traffic and noise levels
d) Application of low noise road surfaces where major resurfacing was taking place
e) Designation of 8 urban quiet areas

ACKNOWLEDGEMENTS

The authors would like to thank Dublin City Council for the use of the data.

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