Field Measurements in the Development of Methods for the Assessment of Low Frequency Noise.*

D Waddington, A T Moorhouse and M Adams
Acoustics Research Centre, University of Salford, M5 4WT
E-mail: d.waddinqton@salford.ac.uk

A procedure for the assessment of Low Frequency Noise (LFN) by Environmental Health officers has recently been developed in the UK. The development of the assessment method included laboratory test, interview-based questionnaires and field measurements. The results of the field measurements are presented in the form of frequency analyses and time histories. The examples are likely to be of particular interest to Environmental Health officers involved in the assessment of low frequency noise complaints.

1. INTRODUCTION

Moorhouse et al. recently described a methodology for the assessment of an LFN complaint produced as part of a UK government funded project [1]. This followed a comprehensive review of the research into LFN and its effects by Leventhall [2]. A complimentary set of field and laboratory studies were conducted by Moorhouse et al. [3] from which a procedure for the assessment of LFN complaints was eventually derived [4]. There are two aspects to the procedure:

- comparison of the level of recorded sound with a 1/3 octave band criterion curve
- evaluation of the correlation between the recorded sound and a complainant's log.

Field trials [5] were subsequently carried out with Environmental Health officers (EHos) to test the workability and usefulness of the procedure for assessing LFN complaints.

This paper presents aspects of the original field measurements performed in the development of the procedure for the assessment of low frequency noise complaints. The overall aim of the field measurements was to provide a database of field data for the development of a proposed criterion. Specifically this involved collecting data with which to test proposed criteria, and to provide audio recordings for use in the laboratory tests. Human reaction to sound is known to be dependent not just on the sound itself [6], but a complex array of other factors like personal associations of the sound. Furthermore LFN cannot be reliably evaluated on the basis of the investigator's experience, since officers investigating the case of LFN may not themselves be able to perceive the sound. Consequently, the procedure for the assessment of LFN complaints requires detailed acoustical monitoring over a period of three to five days combined with a synchronized log completed by the complainant. In each field study the sound measurements were supported by questionnaires to determine whether sociological or other factors might influence the results [7]. Subjects were asked to complete a log sheet giving comments on how they perceived the sound at particular times. Correlation of the comments with the acoustical measurements forms the basis of the procedure for the assessment of the LFN complaint.

Cases were solicited through

*Reprinted with kind permission from the Journal of Low Frequency Noise, Vibration and Active Control

Environmental Health Departments by circular letter, and by specific approaches to Local Authorities known to have a problem in their area. More than forty cases were evaluated. EHos who offered cases were approached by phone and asked for a detailed description of the case. In some cases it was also appropriate to approach the complainant at this stage. A few cases also came in by word of mouth directly from sufferers. EHos and sufferers alike were generally keen to participate. Both groups were told that we were not intending to solve their particular problem, but rather to contribute to improved methods of evaluation in general. We adopted a policy that data collected would not be released to either party, since this could have caused political complications. Whilst all were generally anxious to solve their problem, which in most cases had defied resolution, they were generally happy to participate on the grounds that the results might help others in the future. Participants, both EHos and sufferers, were generally extremely co-operative and helpful.

Cases where the complainant was felt to be reasonably objective and perceptive in their judgement of the sound were selected where possible. Cases where several complaints occurred in a cluster were selected in preference over those where a single complainant lived alone. This was because it is easier to justify the complaints as reasonable if there are more than one. Also, it is well known that cases often arise where no problem can be identified from recordings, and it was thought that selecting clusters would help to avoid such cases.

Cases where there was a long history to the problem, particularly if there had been modifications to a noise source during that time, were generally avoided. This is because such cases can become overlaid with complications that make it more difficult to determine if the responses are purely due to the noise. For example, a number of cases were received in which a low frequency noise source had been identified and noise control work had been carried out to the satisfaction of most residents, but where a smaller number had continued to complain afterwards. One possible cause of this is that the complainants had become sensitised whilst the noise was present. Whilst such sensitisation is a genuine part of low frequency noise cases, it becomes more difficult to classify the response as typical and so stronger conclusions could be obtained by excluding such cases. In all cases, the background noise levels in the residences were remarkably low. Such low levels of natural masking noise are thought by some to be a factor contributing to the disturbance of LFN. Details of the analyses are presented in the project report [3]. The following cases were selected to present the main features likely to be of interest to Environmental Health officers involved in the assessment of low frequency noise complaints.

2. FIELD TRIAL MEASUREMENT METHODOLOGY

In this series of investigations, a single microphone was positioned at a point in the room where the complainant indicated the sound was present. Measurements were made using 01dB Symphonie systems and parameters recorded included 1/3 octave spectra and audio. The microphone and measurement chain were calibrated down to 1Hz against a traceable standard at the UKAS accredited Calibration Laboratory at Salford University immediately prior to the tests. Data were streamed directly to hard disk and subsequently written to DVD discs for archiving.

The complainant determined the measurement position and the microphone was located precisely

within a few centimetres, since low frequency sound levels can vary significantly with position in a room. An unoccupied room was used for preference since there will be less interference from internal sounds, and recordings were usually made between 21h00 and 09h00. In addition to making physical recordings of the sounds within complainants' residences, it was necessary to obtain a significant amount of personal data about the individuals themselves using a comprehensive one-to-one semi-structured interview schedule. The equipment was left to monitor unmanned for between 3 and 7 days. Subjects were asked to complete a log sheet giving comments on how they perceived the sound at particular times.

A certain amount of judgment was involved in identifying the various low frequency sources. A useful technique that is now becoming more widely available is to take audio recordings along with sound level measurements. Audio recordings were played back at a higher level to distinguish between various noise sources. Combined with third octave and narrow band spectra, this provided the most successful identification of sources.

A large amount of data was recorded for each case study. This was considered necessary since from experience the equipment must typically be in the property for several days to capture a period when the complainants report hearing a representative 'bad' noise. One of the problems of LFN analysis is how to make sense of such a large amount of data. The details of the analysis varied from case to case, but the usual steps were as follows:

a. Several periods were selected from the subject's log about the time they said the noise was particularly bad, the period was chosen to encompass the time given by the occupant, but to exclude events such as doors closing etc. as detected by ear.
b. For each such period a sonogram was drawn to display the 1/3 octave spectrum. This was examined to see whether any events could be identified that correlated with the respondent log. The sonogram option may not be available to most EHos, but a third octave band spectrum can be used instead.
c. From the third octave band plot, the single third octave band that exceeded the audibility threshold by the highest margin was selected
d. A narrow band plot was also made to see if there were any obvious tonal frequencies in this band
e. A plot of the sound level in this third octave band was then plotted against time so as to show what, if anything, happened at the time identified as being bad.

In all but two cases it was possible to identify suitable periods described by the subject as particularly bad. In one case the subject did not make a detailed log, asserting simply that their noise was present all the time. In another there was some question as to whether it was the subject themselves or a spouse who had compiled the logs. For these cases we selected the worst-case situation by a combination of looking at the spectra and analysis 'by ear' of the audio recordings.

Following analysis the case studies fell into three categories:

1. Positively identified LFN - in these cases the national criteria of Germany, Denmark, Sweden, Poland and the Netherlands were exceeded and respondent logs correlated with recorded sound from an external source of low frequency noise. In these cases it can be said that an environmental sound has been identified as likely to be responsible for the complaints.
2. Marginal - in these cases a source

Table 1 Categorisation of case studies

Environmental sound category	Number of cases
Positively identified	3
Marginal	3
Unidentified	5

of low frequency noise could be determined but was borderline with respect to the national criteria. In addition, the respondent logs did not correlate with any source. In these cases it cannot be said whether the environmental sound that has been identified is likely to be responsible for the complaints.

3. Unidentified - in these cases the national criteria were not generally exceeded, except perhaps by traffic noise or sound from internal domestic equipment, and respondent logs did not correlate with any source. In these cases it can be said that no environmental sound was identified that could be responsible for the complaints.

Examples of each of these categories are given in the results below.

3. RESULTS

3.1 CATEGORISATION OF CASE STUDIES

In the field studies, ten independent cases of reported LFN were investigated, as well as five control cases where no complaints had been received. Three cases were identified where the criteria were exceeded and there was correlation between the residents' logged complaints and the low frequency noise level. Two of these three cases were related having been measured in the same apartment block. Five cases were unidentified where the criteria were not generally exceeded and there was a lack of correlation between comments and noise levels. Analysis of these eight cases using the procedure for the assessment of LFN complaints was straightforward. However, three cases were marginal in that the measured low frequency noise was close to the criterion in level, and moreover, did not

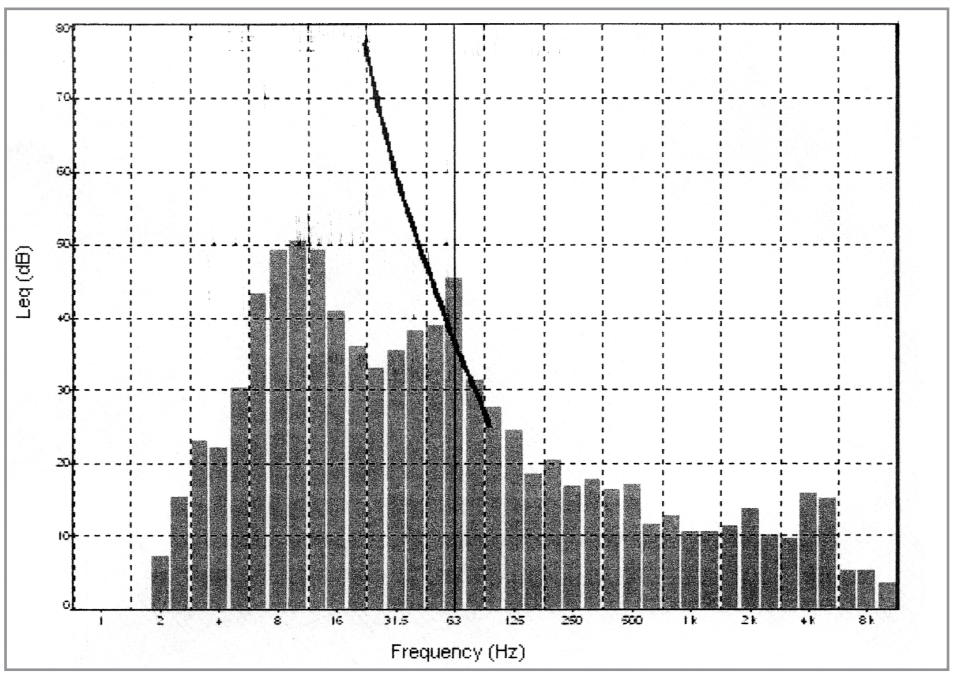

Figure 1 1/3 octave band spectrum averaged over 9m30s starting 07h00m. The solid line is the hearing threshold according to ISO226(2003).

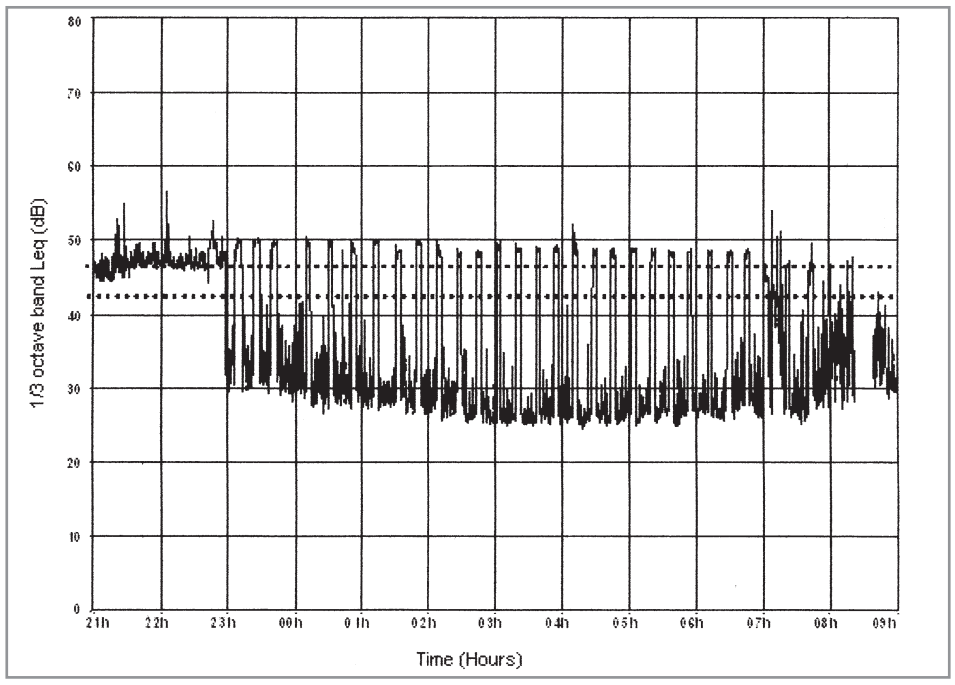

Figure 2 *Time history showing 63Hz 1/3 octave spectrum band with daytime and nighttime criteria*

correlate with complainant comments. Investigation of these marginal cases was found to be most time-consuming.

3.2 ENVIRONMENTAL SOUND IDENTIFIED

This case study took place in an apartment in a quiet urban area. Figure 1 shows a 1/3 octave band spectrum calculated over one of many periods identified by the complainant. Comparing with the criterion curve it is seen that the 63Hz 1/3 octave band predominates. Figure 2 shows a time history of the measurements in the 63Hz 1/3 octave spectrum band, and it is evident that a source cycles on and off with periodicity of about 10 minutes on and 20 minutes off. Also shown in the time history are the 63Hz daytime and nighttime criteria from the procedure for the assessment of LFN complaints. Whilst the background level during the nighttime is well below the criterion, the source levels clearly exceed the criterion. Given the correlation of the complainants log with these recordings these results indicate that this source is likely to be the cause of the complaints.

3.3 NO ENVIRONMENTAL SOUND IDENTIFIED

This case study took place in a house in a quiet urban area. Comparing the spectrum of Figure 3 for one of the many periods identified by the complainant with the criterion curve, it is seen that no particular 1/3-octave band dominates. The 63 to 100Hz bands may just be audible, but the dominant source in this part of the spectrum was found to be road traffic. This is fairly common. Figure 2 shows a time profile of the measurements in the 80Hz 1/3 octave spectrum band. The profile of the sound levels during the night is typical of traffic. Occasional spikes on this plot are due to domestic movement or traffic events and are not associated with any steady low frequency noise. Also shown in the time history are the 80Hz daytime and nighttime criteria from the procedure for the assessment of LFN complaints.

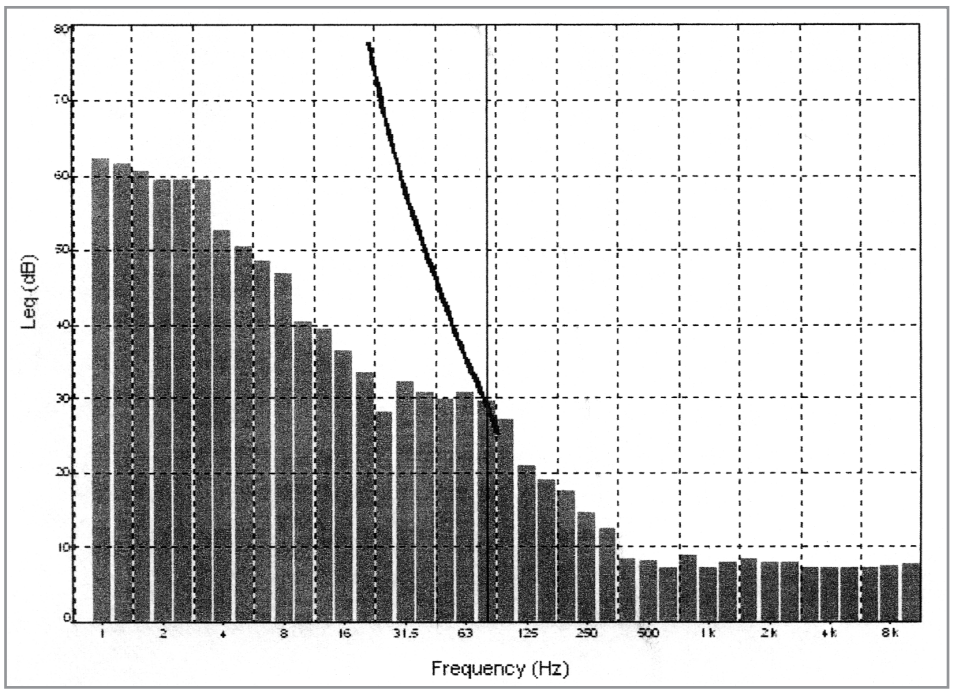

Figure 3 *1/3 octave band spectrum averaged over 9m30s starting 19h30m. The solid line is the hearing threshold according to ISO226(2003).*

Whilst the background level during the nighttime is well below the criterion, daytime levels are also seen to be remarkably low. More detailed frequency analyses were also performed, and several other times were evaluated. However no relationship between noise levels and the complainants log could be established. Given the exceptionally low levels as compared with the criteria and the lack of correlation between the complainants log with these recordings, these results indicate that no environmental source was measured that is likely to be the cause of the complaints. The cause of the complaints in this case remains unknown.

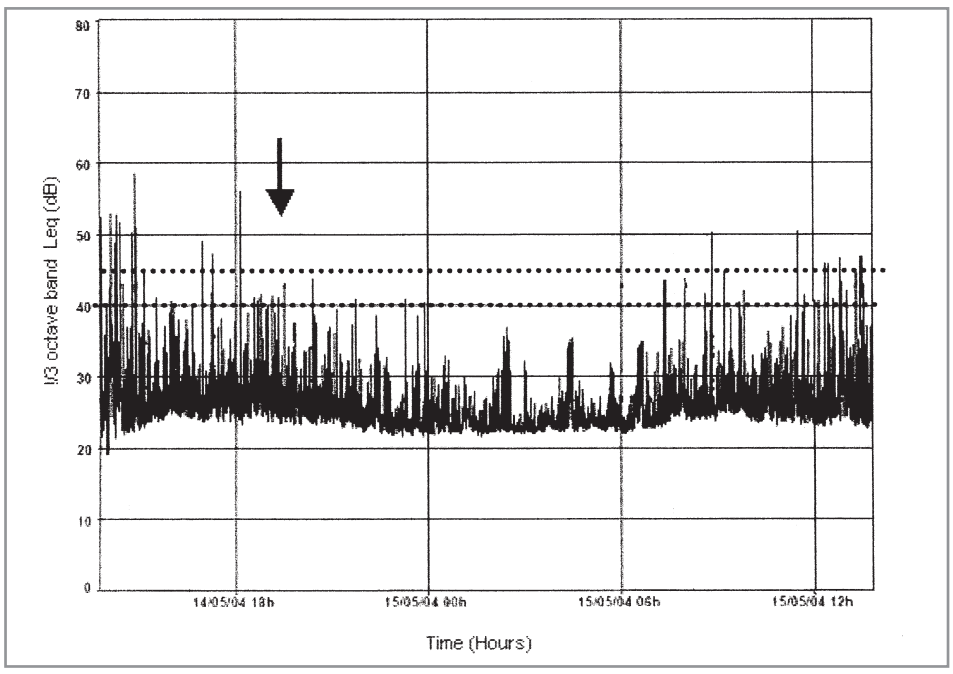

Figure 4 *Time history showing 80Hz 1/3 octave spectrum band with daytime and nighttime criteria*

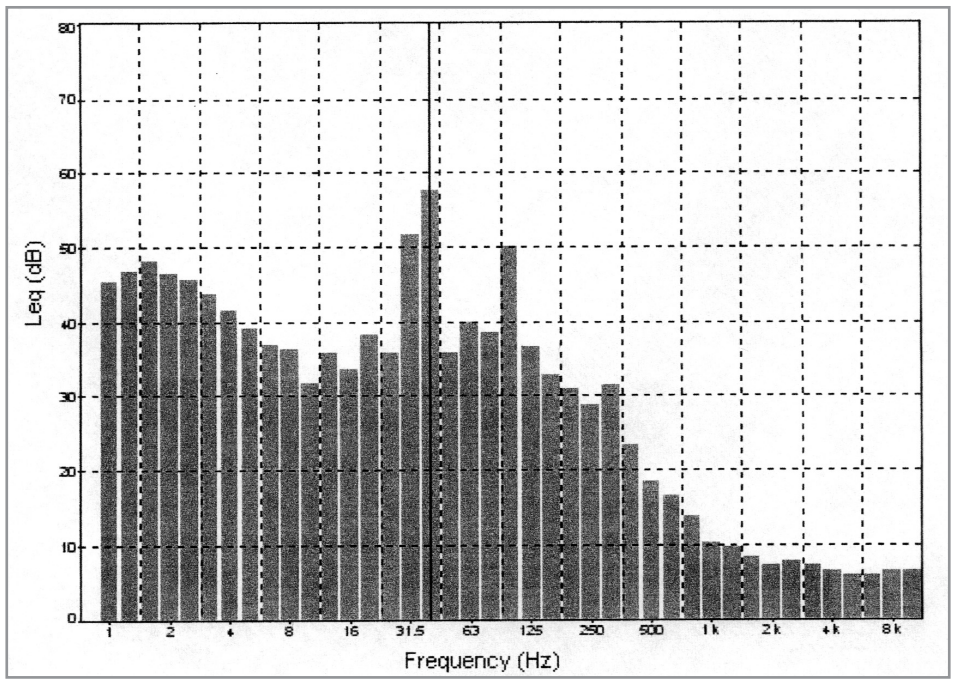

Figure 5 1/3 octave band spectrum averaged over 9m30s starting 06h00m

3.4 CONTROL CASE

Five control cases were also examined using the same techniques as for the case studies. These were residences where low frequencies might be expected in the spectrum but where there had been no reports of disturbance. The control case detailed here took place in a suburban detached house with direct line of sight to a busy motorway. Figure 5 shows a 1/3-octave band spectrum from one of many periods identified from the analysis as containing low frequencies, and Figure 6 one shows a time history of the measurements in the 40Hz 1/3 octave spectrum band. It is seen that the noise from a domestic heating pump dominates in the 40 and 80 Hertz 1/3 octave bands at levels that exceed the criterion curve. Whilst the background level during the nighttime is well below the criterion, the source levels clearly exceed the criterion. There were however no complaints about LFN.

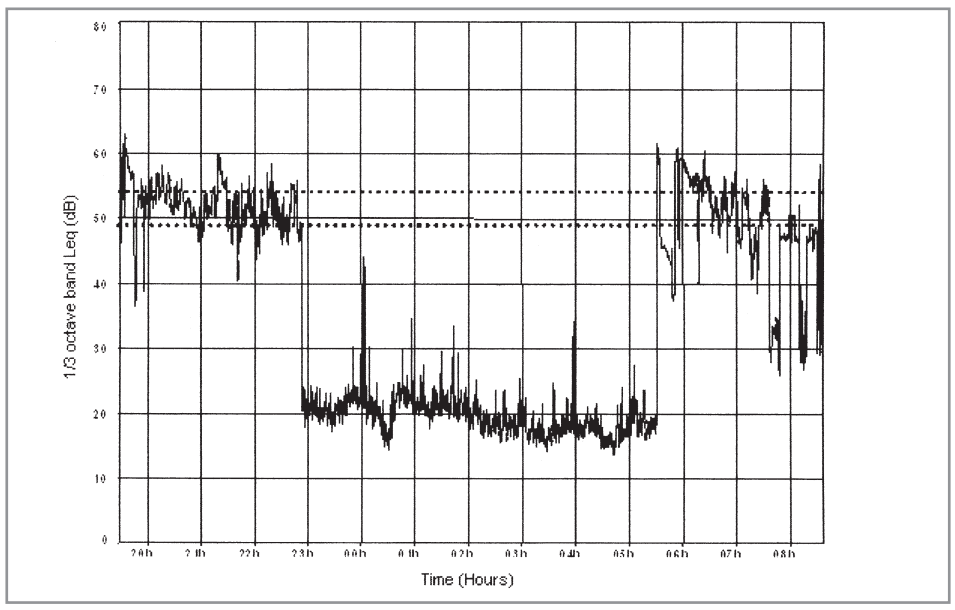

Figure 6 Time history showing 40Hz 1/3 octave spectrum band with daytime and nighttime criteria

4. DISCUSSION

Low frequency noise is often measured at the extreme of the usable frequency range of the instrumentation, and so special care is required to ensure the reliability of the results. During the initial stages of this work much effort was placed in obtaining and calibrating microphones and instrumentation to measure accurately noise levels to frequencies as low as 3Hz. It transpired through these field trials that most environmental sounds responsible for LFN complaints occur around 40Hz or higher, frequencies well within the accurate range of the modern sound level meters used by most Environmental Health officers. If the meter has a UKAS calibration certificate this usually means that it underwent the 'verification' procedure for sound level meters according to BS7580 Part 1 (1997) on the date of the certificate. In the verification test the lowest frequency for a full acoustic check is 125Hz: third octaves down to 31.5Hz are checked electrically but not acoustically. This is sufficient for the majority of sound measurements, and is also satisfactory for low frequency noise in most cases. However, there is no guarantee of accuracy without an acoustic check at the frequency being measured. An acoustic check at lower frequencies than is normally carried out during verification is therefore advisable if possible. This could be achieved for example using a calibrator such as a multi-frequency calibrator which itself has a traceable calibration at low frequency, or by making a special request to a calibration laboratory.

Although the majority of environmental noise standards specify that sound measurements should be conducted outside, it is now generally agreed that low frequency noise can only meaningfully be evaluated inside dwellings. However sources within the dwelling can generate noise at low frequencies. Domestic equipment may produce a low frequency noise that can appear on recordings and measurements. In particular, fridges produce a tone, typically between 49 and 50Hz that cycles in and out with a period of between 5 and 60 minutes. Furthermore, whilst not identified as noise nuisances, the interaction within dwellings of tones generated by domestic equipment with transportation noise has been recorded and reported [8].

It is recommended that when assessing LFN complaints, since to turn off equipment may produce untypical conditions that could make it more difficult to identify the cause of a disturbance, domestic equipment should be left running. However, a set of preliminary recordings should be taken with all such equipment on and off in turn for a few minutes, to allow identification of the level and character of the sound produced by each at the measurement location. The best time to conduct these tests is immediately after the instrumentation is installed and prior to any unattended measurement.

Although LFN complainants have been shown to be no more sensitive than the general population on average, in relative terms however they are the more sensitive group in that they set acceptability thresholds closer to their threshold of hearing [3]. During these field trials, there were no cases in which the LFN was reported to be present only during the day. Furthermore, in every case the noise was reported to be present at night. This contrasts with common experience where a random selection of general industrial noise complaints might be expected to include some complaints about industry that does not operate at night that causes disturbance in the daytime. This does not mean that the noise was absent during the day though, since most respondents said that while sound could be heard during the day it was worse at night.

Until recently it has been extremely difficult for Environmental Health officers to deal with complaints about LFN. This was in part because specialist skills and equipment are needed and partly because no official guidance was available to support them. LFN is now a recognised problem in many countries in the world. A relatively small number of people are affected but those who are tend to suffer severe distress. The DEFRA procedure for the assessment of low frequency noise complaints [4] has addressed this latter point. Although this procedure is now becoming reasonably well established, this does not mean that the causes of LFN suffering are fully understood and many cases still go unexplained.

The procedure is designed to help separate cases where it is clear that an environmental noise correlates with the complaints from those where no noise exists that is within the power of the local authority to control. Concern has been expressed over the approximately 50 per cent of cases in this study where no environmental source could be detected that could be responsible for the LFN complaint. On these occasions when no environmental sound has been found to be responsible for the complaints, the case cannot be resolved by engineering noise control. This is not to say that raised low frequency environmental noise levels will not be recorded, as was demonstrated by the control case above. However, since there is no correlation between the complainants' comments and the presence of any dominant frequency components reduction in these noise levels would not resolve the complaints. Nevertheless feedback from Environmental Health officers taking part in field trials of the procedure has been very positive, indicating that the procedure was easy to follow and strengthened the authority's position with the complaint. Furthermore, complainants were said to be significantly reassured once they saw that a detailed procedure was being followed

5. CONCLUSIONS

These results illustrate that when assessing LFN complaints there is no substitute for in-situ measurement. In rare cases, where the low frequency noise is obvious and continuous for example, it will be possible to carry out an assessment on the spot. In most cases however, a period of unattended monitoring will be required. If possible, recordings should be made continuously for a minimum of three days since the complainant's response can be affected by the presence of the equipment and is often untypical immediately after it is installed. The ability to record audio samples is not essential, but it is a distinct advantage when it comes to the analysis so should be considered highly desirable However the recording of audio samples should be discussed with the complainant since this could raise matters of confidentiality. An ability to produce narrow band frequency plots can also be advantageous.

Field trials of the measurement and analysis process have concluded that the procedure was both workable and useful for the assessment of LFN complaints. Investigators have generally been able to draw firm conclusions from their cases. Moreover there was a strong consensus that it was mutually beneficial for investigating officers and for complainants. However the procedure is intended to assist in the evaluation of existing problems. It is not intended as a means of predicting when disturbance might occur, for example in a planning situation, and would not be reliable to use as such. This is because disturbance by LFN depends on a number of factors, such as the character of the sound, whose effects are neither well understood, nor readily

predictable. As illustrated by the control case detailed above, levels of sound above the criterion curve produced by this work are frequently found to be acceptable. Conversely a good proportion of complaints are made with environmental sound levels below the average threshold of hearing. These observations indicate that no generic approach to prediction of LFN disturbance based on environmental sound levels appears to be possible.

It was not the intention of this work to provide guidance in locating the source of a LFN. However, it is usually found that the most difficult part of an assessment is in determining the existence or otherwise of a sound that correlates with the disturbance, and if this can be established then the source can usually be found. Thus, it is expected that, whilst not a specific aim, the procedure outlined here will form a significant step in the diagnosis of cases requiring treatment.

ACKNOWLEDGEMENTS

The authors are grateful to DEFRA for funding the work leading to this paper. We would like to thank all the participants of the field and laboratory studies as well as the Environmental Health officers who performed the field trials of the procedure and provided many useful comments.

REFERENCES

1. A. T. Moorhouse, D. C. Waddington, and M. Adams, "Methodology for assessment of a LFN complaint" Proceedings of the Institute of Acoustics Volume 27 (3), 2005.

2. G. Leventhall, A Review of Published Research on Low Frequency Noise and its Effects. Research project report 2003 http://www.defra.gov.uk/environment/noise/research/lowfrequency/pdf/lowfreqnoise.pdf

3. A. T. Moorhouse D. C. Waddington, and M. Adams, "Proposed criteria for the assessment of low frequency noise disturbance," Research project report 2005, http://www.defra.gov.uk/environment/noise/research/lowfrequency/pdf/nanr45-procedure.pdf

4. A. T. Moorhouse D. C. Waddington and M. Adams, "Procedure for the assessment of low frequency noise disturbance," Research project report 2005, http://www.defra.gov.uk/environment/noise/research/lowfrequency/pdf/nanr45-criteria .pdf

5. A. T. Moorhouse D. C. Waddington and M. Adams, "Field trials of proposed procedure for the assessment of low frequency noise complaints," Research project report 2005, http://www.defra.gov.uk/environment/noise/research/lowfrequency/pdf/nanr45 fieldtrials.pdf

6. A. T. Moorhouse, D. C. Waddington, and M. Adams, "The effect of fluctuations on the perception of low frequency sound," 12th Intemational Meeting on Low Frequency Noise and Vibration and its Control, Bristol, UK, 18 - 20 September 2006

7. M D Adams, A T Moorhouse and D C Waddington, "Social effects of low frequency noise exposure on sufferers: developing a procedure of assessment," 12th International Meeting on Low Frequency Noise and Vibration and its Control, Bristol UK, 18 - 20 September 2006

8. D. C. Waddington and A. T. Moorhouse, "Interaction within dwellings of transportation noise with tones generated by domestic equipment," Proceedings of the Institute of Acoustics Volume 28 (1), 2006.

COUNTY POLICE ENFORCE STATE LAW

Anne Arundel County police (MD, USA) plan to increase the number of officers devoted to getting residents to turn down the volume, after the county's recent adoption of the tougher state noise pollution laws has been met with a jump in complaints ranging from barking dogs to clanging trash trucks. In the next two months, the county will form an informal noise abatement unit, with two officers in each of the police department's four districts pursuing complaints, said Cpl. Brian Smith, a traffic coordinator who carries a noise meter as he travels the county. Since July, Smith said he has handled about four to six calls a day. He can fine people up to $10,000 for exceeding 55 decibels from 11 p.m. to 7 a.m., and 65 decibels at other times. "A lot of people didn't know what the law was," Smith said. "In most cases, they're very happy to comply. We haven't had to charge anybody." The elimination of the sole state sound inspector in 2005 for budgetary reasons put the burden on local jurisdictions to revise and enforce their noise-pollution laws. County law prohibits the operating of a radio, machine, tool or similar device that generates an unreasonable sound that can be heard 50 feet away within a residential district. Anne Arundel County reached an agreement in July with the state Department of the Environment that allows the county to enforce the state's noise laws. County Executive John R. Leopold pushed for the increased authority as part of a package of nuisance enforcement options that he said will curb activity with the potential to foster more serious crimes. "If left unattended, these nuisance crimes form a breeding ground for more serious crimes," said Leopold, a Republican. "It's like the 'broken windows theory' if criminals see a broken window or a trashy yard or graffiti, they'll assume its safe for them to commit more serious crimes." The county police now have five decibel meters and are pushing to educate residents about what's too loud.

ATTENTION DEFICIT AND NOISE

Background noise may help unruly schoolchildren pay attention in class, new research suggests. The discovery was made by Swedish scientists who tested a group of children diagnosed with attention deficit and hyperactivity disorder (ADHD). Normally children with ADHD are hard to control and easily distracted. But far from putting them off, the presence of noise seemed to help them concentrate. The same was true of children with no behavioural disorder but who under-achieved at school. In contrast, brighter pupils without ADHD were put off by noise and performed better in silence. A group of 42 children aged nine to 13 took part in the first test, half of whom had ADHD. The children were read a list of 96 simple verbal command sentences which related to actions, such as "roll the ball" or "break the match". They were then asked to recall as many of the sentences as they could. Normal children remembered more sentences when the task was carried out in silence. But those with ADHD did better when subjected to white noise - a whooshing sound similar to the static from a radio tuned between stations.

DUBUQUE

It all depends on the type of noise and the time of day as to whether the Health Services or Police Department will handle the noise complaint. The Health Services Department handles environmental noise complaints between 8 a.m. and 5 p.m. These noise complaints can range from excessive construction noise before construction crews are allowed to work, to operating a lawn mower before 8 a.m. The Police Department handles noise complaints if they occur outside of the Health Services Department's hours or are complaints such as loud mufflers and music. Both departments work to be proactive and issue citations as a last resort. "We typically work with the people and educate them on the noise ordinance," said Mary Rose Corrigan, public health specialist with the city of Dubuque." Assistant Dubuque Police Chief Terry Tobin agreed with Corrigan and said the Police Department gives out a lot more warnings than citations.

MOSCOW

A new report produced by Moscow's Environmental Health Service has found that noise pollution in Moscow has reached critical levels. Seventy percent of Muscovites live in unacceptable noise conditions according to the report, which points to the detrimental effects of traffic and construction noise on the city's health. The Environmental Health Service receives more than 300 complaints a year about excessive noise – a figure that is growing by about 12 percent every year. Ninety percent of the complaints are about transport and construction work, the rest are concerned with noisy restaurants and bars, or neighbours who play their music too loud. Muscovites who are affected by noise can currently ring a 24-hour hotline and a team of experts will assess the level and decide whether it is acceptable. But officials admit the service is limited. The team consists of just seven people, who monitor sound levels across the city.

TOKYO PARK FOUNTAIN

A fountain in a Tokyo park has been turned off after the Hachioji branch of the Tokyo District Court ruled that noise levels of children playing in it exceeded permitted decibel levels. The ruling was made after a local woman receiving medical care filed an application for a provisional injunction to put a stop to noisy children playing in the fountain at Ikoi-no-Mori Koen park in Nishi-Tokyo. The complainant suffers from arrhythmia and insomnia and claimed that the voices of the children playing in the water disturbed her and caused her physical pain. The city government criticised the ruling, saying that as children's voices cannot be said to be noise and no other residents had complained, the noise level was not intolerable, even if it exceeded the official level. The branch court ruled to prohibit the operation of the fountain as the volume of children's voices near the woman's home exceeded the permitted level, saying that a fountain around which children would not raise their voices—such as one in which they cannot play—could have been built. "Noise issues are currently drawing increasing concern, and city authorities should pay closer attention," the woman's lawyer said.

BRINGING DOWN THE HOUSE

Loud rock concerts may be getting some of Britain's most treasured historic buildings all shook up, new research suggests. A study at Hampton Court Palace found signs of window fittings loosening because of the sound vibrations. Bangs from firework displays held in the palace grounds also had an impact on windows, as well as mirrors and other objects mounted on outside walls. The research conducted at Hampton Court raises fears that pop and rock events held at many historic locations may be putting fragile old buildings at risk. Every June the palace near London hosts a three-week music festival attended by 2,500 people each night. The event is held in the inner courtyard of the palace, known as Base Court. It attracts major rock, pop and classical stars, who this year included Bryan Ferry, Tom Jones and opera tenor Jose Carreras. Conservation scientist Dr Ian Gibb, who led the study, said: "Anecdotal evidence had been reported of windows and brickwork in Base Court being affected, although we were never able to attribute this to acoustic vibration from the music festival." Sensors showed that vibration from the music did affect windows close to the stage especially those already suffering from some decay. "Bass frequencies, usually greater for pop concerts versus classical concerts, were found to increase the risk of damage," said Dr Gibb. The evidence for harm to brickwork was less certain but it was possible that music vibrations might worsen pre-existing problems such as frost damage.