How to find the source of low frequency noise: three case studies

Carel Ostendorf
Cauberg-Huygen Raadgevende Ingenieurs BV
Postbus 480 6200 AL Maastricht
The Netherlands
c.ostendorf@chri.nl

Received 21st January 2009

ABSTRACT
When people are annoyed by low frequency noise, their first concern is to stop the noise. Therefore it is necessary to find the source of the noise. Unfortunately, not in every case is the source very obvious. In most cases a lot of potential sources are available both inside and outside the building. Of course in theory it is possible to find the source by switching on and off all the potential sources but in practice this is not always practicable.
In this paper three cases of possible low frequency noise are presented in which different methods of finding the source have been used. In all these cases the nuisance is present in a domestic situation and has been going on for several years. Some of the residents suffer from mental problems due to the unwanted noise. Using the measurement results the searching methods are discussed and evaluated.

1. INTRODUCTION
In the second half of 2004, the south of the Netherlands was bothered by a mysterious hum. More than 300 people living in a rather large area complained about the nuisance of low frequency noise. So far, the source has never been found [1]. In the beginning of 2006 the west of The Netherlands had a similar problem. Despite a lot of measurements, the source is still not found. If the source is unknown, the search for it is one of patience, endurance and financial sacrifices. Because there are a lot of possible sources such as fans, air conditioning devices, cooling systems, pumps, burners or diesel engines, one does not know where to start. Cauberg-Huygen has developed a schedule which can be followed to find the source. This schedule is discussed in section 1 followed by three cases of low frequency noise. Finally the schedule is evaluated and some changes in the schedule are implemented.

2. METHODS OF FINDING THE SOURCE
Just by listening to low frequency noise, it is very hard to determine what causes the noise. It is even hard to determine if the source is inside or outside the building. The first goal is to find out if the source is inside or outside the building. Several measurement techniques are available such as:
- man-controlled sound measurements
- unmanned logging sound measurements
- measuring inside and outside the building simultaneously
- noise and vibration measurements simultaneously
- spectral analysis (FFT and CPB 1/24 octave)

Once it is clear if the source is inside or outside the building, other techniques are used to actually find the source. Figure 1 shows a schedule that was used during the three cases described here.

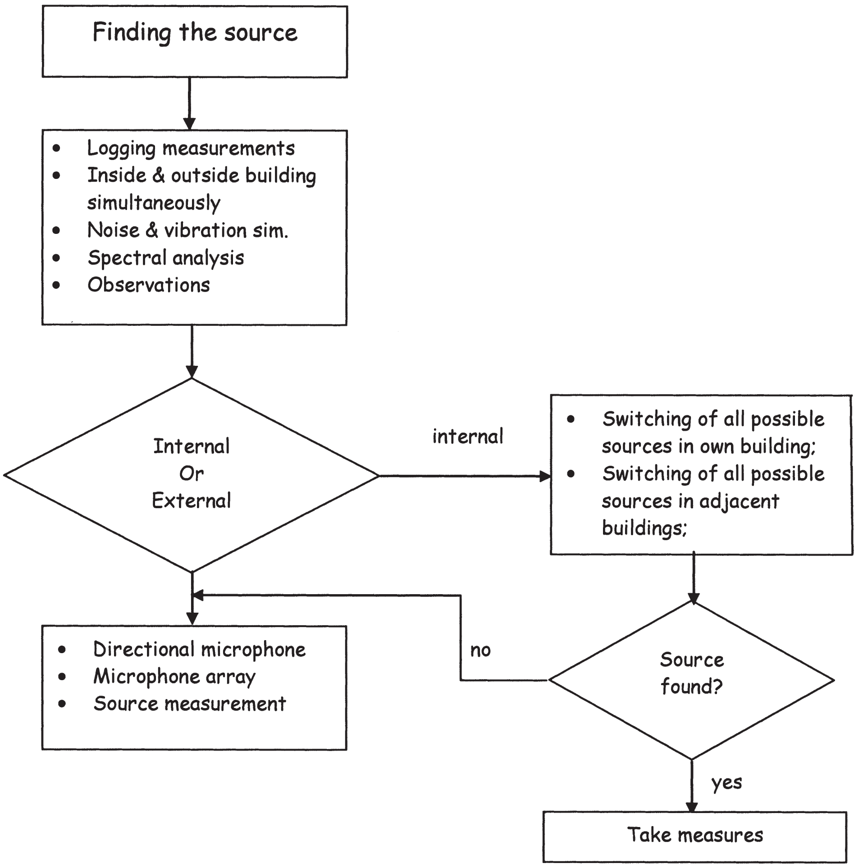

Figure 1 Schedule of finding the source

3. THREE CASES

In the summer of 2004 and the beginning of 2006, three cases of low frequency noise (LFN) were studied. All three cases will be discussed. In order to protect the privacy of the people involved, the cases are made anonymous and therefore called case 1, 2 and 3.

3.1 Case 1

This case is situated in a small village located in a valley near two busy motorways. The family involved consists of two adults and two children. Both parents (in their forties) are annoyed by low frequency noise. The children (teenagers) do not hear the noise. The family live in the outer home of a building which consists of 4 homes. Figure 2 gives a schematic overview of the situation.

During the first visit to the family, they explained that the nuisance started during or after building activities in the nearby hospital. From the moment they have been aware of the noise, the family has tried all kind of things to keep the noise outside their home: additional sound isolation by replacing the glass in the windows, additional sound isolation in walls and ceiling and the use of ear mufflers. Sleeping is a problem and the only place in their home where they manage to sleep is in the uninsulated attic. Due to the masking effect of the traffic noise they don't hear the noise that much, but during the quiet hours of the night this is not helpful. The family have already experimented by switching off the power in their own home and in their first neighbour's home but this did not eliminate the noise. They are convinced that the source of the noise is located outside their home.

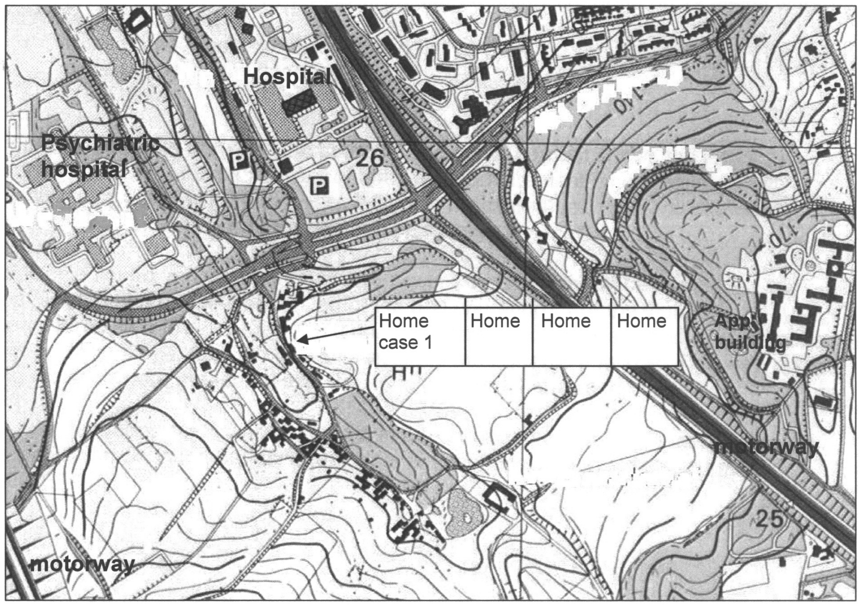

Figure 2 Situation case 1.

To tackle the problem the following strategy was used:

1. manned sound and vibration measurements to find the frequency or frequencies that are causing the noise;
2. evaluation of the measurement results to determine whether there is a legal ground to proceed;
3. manned sound and vibration measurements near possible sound sources (large technical installations for cooling, heating or ventilation) in or on top of buildings in the surrounding area

3.1.1 Sound measurements

In the night of the 9th of June 2004 between 01 :30 and 04:30 sound measurements were carried out using a Bruel & Kjaer portable analyzer 2144 in combination with a ½ inch microphone type 4165. Although the noise was not audible to the technician, the family heard the noise very clearly. Measurements were done on locations where the noise was heard best:

1. in the corridor between kitchen and hall;
2. in the big bedroom close to the bed;
3. in the cellar.

Figure 3 shows the result for the corridor. The measurement shows the average sound level (L_{eq}) during 4 minutes of effective measurement time. The spectral analysis was done in $1/24^{th}$ octaves. With this measurement a general impression of the relevancy of certain frequencies can be obtained.

Additional sound and vibration measurements were done in the bedroom near the bed (sound) and on the wooden leg of the bed (vibration). For the vibration measurements a Bruel & Kjaer 4379 acceleration transducer was used in combination with a 2635 charge amplifier and connected to the portable analyzer. This way, sound and vibration were measured simultaneously. Figure 4 shows the result.

No low frequency noise was measured in the cellar and the sound level was very low as well. Later on in the project it was clear why nothing was found in the cellar.

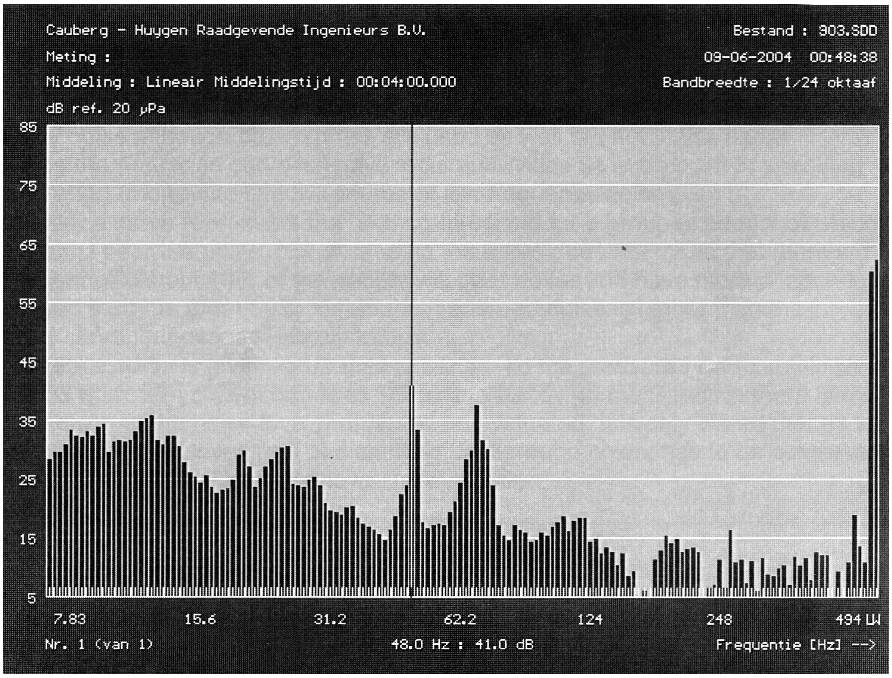

Figure 3 Spectral analysis of noise in corrider between kitchen and hall

Two frequencies were found: 48 and 67 Hz. The level is 41 and 38 dB.

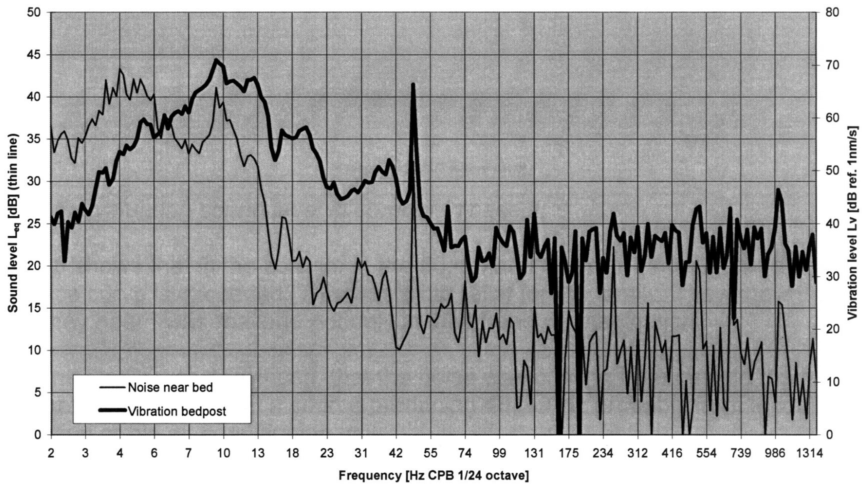

Figure 4 Sound and vibration level in the bedroom.

This time 49 Hz was found. The frequency of 67 Hz was not found.

3.1.2 Evaluation sound level case 1

To evaluate the sound level, the reference curve of the Dutch Directive of Low Frequency Noise [3] is used. There is no law about low frequency noise in the Netherlands. The Directive with its reference curve is generally used to evaluate low frequency noise although other curves are used as well but not in this paper. Exceeding the reference curve can give local authorities an extra push in spending time and effort (money) to find the source of low frequency noise.

The reference curve represents the hearing threshold for a group of people of which 90 % do not hear the noise. Not exceeding the curve does not mean that there will be no nuisance. About 10% of the people will hear better and have more chance to be annoyed than the other 90%. When the measured noise is higher than the reference curve, annoyance is likely to occur.

The reference curve is given in 1/3 octave bands, so the measured noise levels were transferred from 1/24 octave bands to 1/3 octave bands. In the Directive there is no time limit given to the noise level that has to be evaluated. It is only stated that an in time averaged sound level, free of disturbing background noise, has to be compared to the reference curve. Figure 5 shows the evaluation.

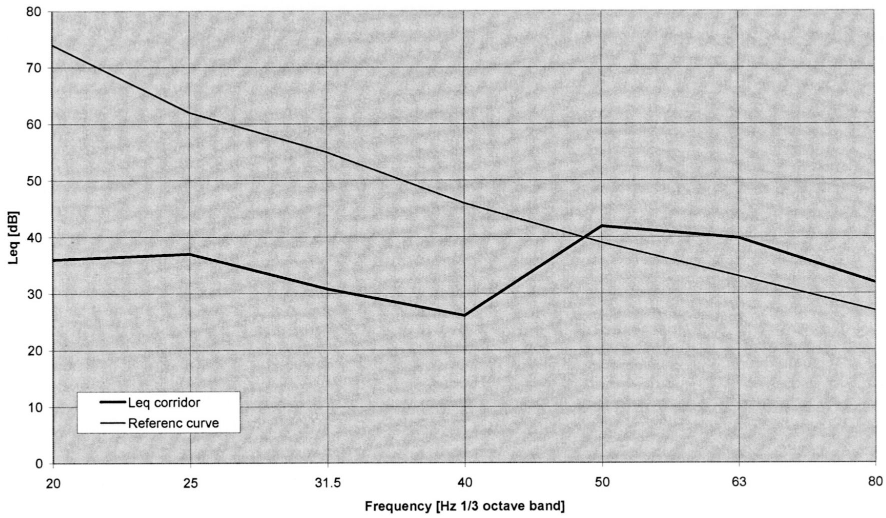

Figure 5 Evaluation sound level in corridor in case 1.

Figure 5 shows that in the corridor in the 50, 63 and 80 Hz 1/3 octave band, the reference curve is exceeded. This was a big relief for the family. They knew that the noise they heard was real and not only in their head or imagination.

Since the family was convinced, that the noise was coming from outside their home, the search was directed at a source producing 48, 49 Hz probably from a cooling installation or big air conditioning unit.

Because the reference curve was exceeded, some kind of legal pressure was possible. So the local authorities were asked to persuade three organisations to cooperate because their buildings had technical installations on the roof. These three organisations were:

1. a hospital;
2. a psychiatric hospital;
3. an apartment building. Luckily all three organisations were willing to cooperate and did not need persuasion.

3.1.3 Searching outside

The annoyance had more or less started since the reconstruction of the nearby hospital. The hospital is located about 400 m north of the home and consists of some tall buildings over 40 meters high with large installations on top. Those installations were the first suspects.

Northwest of the home at about 450 m distance, a psychiatric hospital is located. Although there are no tall buildings, a lot of technical installations are situated on the roof. These installations were also checked.

Finally southeast of the home a tall apartment building is located at about 1000 m distance. Since it is situated on the top of the valley, the noise could reach the home. This building was also investigated.

During one day (18^{th} of February 2005) all the installations were measured. Unfortunately no sound source was found with a relevant frequency component of 49 Hz and enough sound power to achieve the measured sound level in the home.

This was a big disappointment for the family. Was the source located outside their home or was it in one of the adjacent homes?

3.1.4 Logging measurements

In order to get to know more about the performance of the 49 Hz and to know if the sound source was located inside or outside, the noise inside and outside the home was simultaneously measured and logged during two nights in the beginning of April 2005. Two B&K microphones type 4165 were connected to the B&K analyzer 2144. The microphone inside the home was located in the corridor between kitchen and hall, the microphone outside the home was located in a small hole in a window on the east side of the building facing the motorway. This way noise from the hospital and the apartment building was captured. The measurements started automatically at 0.00 hours and ended at 07.00 hours. An L_{eq} was measured every minute and stored in 1/24 octave bands. The analyzer used the main power supply and no battery supply because in the manned measurement it was already established that the power supply did not affect the 49 Hz. From the same measurements it was also clear that switching off the electrical power in the home, did not affect the 49 Hz. Figure 6 shows the result of the logging measurement for the frequency of 49 Hz.

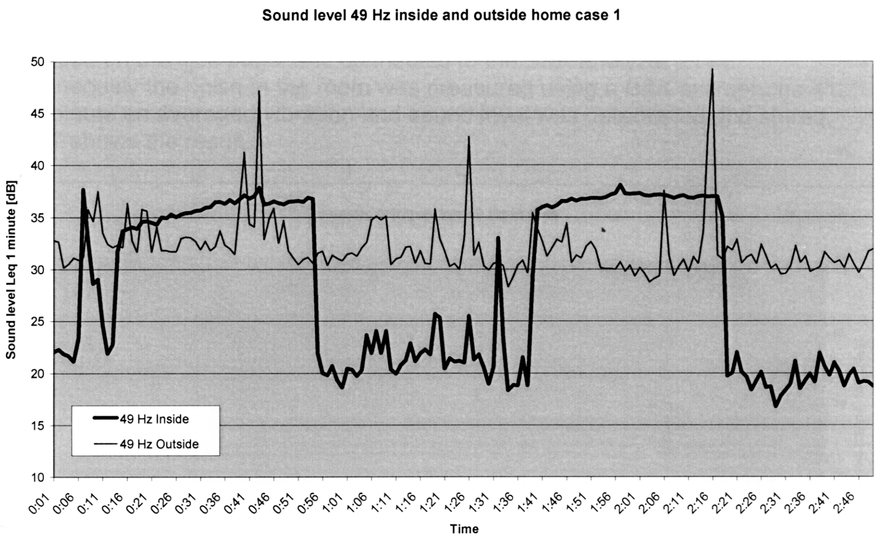

Figure 6 Sound level 49 Hz inside and outside the home measured simultaneously.

Clearly it can be seen that the sound level in the corridor at 49 Hz follows a pattern of switching on and off. The sound level outside the building doesn't show this pattern at all. *The sound source should be inside the building!*

3.1.5 Back inside

During the manned sound measurements, the electrical power of the home was switched off but this did not affect the sound level in the 49 Hz band. The sound source was not in the home of the family but could be in the three houses of the neighbours. Flanking noise or structure borne noise could be relevant for the sound level. Due to the switching pattern it is clear why during the manned measurement nothing special was measured during the measurements in the cellar. The source was switched off at the time.

Unfortunately the contact of the family with its neighbours was not very good and they did not want to get involved in troubles with their neighbours. Furthermore the financial possibilities were expended so it was not possible to do any measurements in the houses of the neighbours.

3.1.6 Other ways to determine the source

Although it was not possible anymore to carry out sound measurements in or near the home of the family, it was still possible to do measurements elsewhere in order to find the type of sound source. To have an idea of the *type* of the source, the measurement results from the logging file were shown to several experts in the field and compared to the literature. From these actions it was concluded that some kind of cooling system was most likely to be the source. Since the cooling system should be of a domestic kind, a refrigerator or freezer were the first sources of investigation. If those sources were placed against the wall, structure borne noise would be induced.

In another home, sound and vibration measurements were done. On a domestic refrigerator-freezer combination (type AEG Oko Santo), a B&K 4379 accelerometer was placed on the side panel and connected to the B&K analyzer 2144. Simultaneously the noise in the room was measured using a B&K microphone 4165. Every minute an averaged vibration and sound level was determined and stored. Figure 7 shows the result.

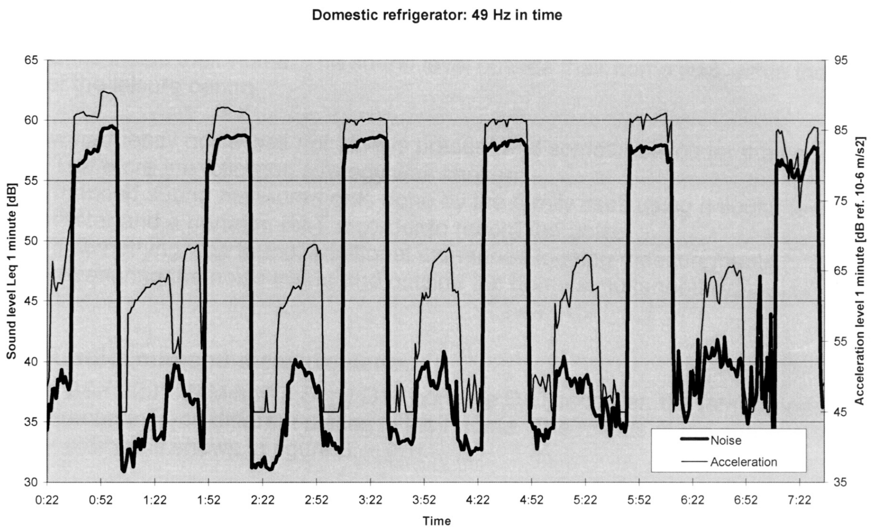

Figure 7 Sound and vibration level of a domestic refrigerator.

The pattern found in this measurement is very similar to the pattern in figure 6. The pattern is best seen in the 49 Hz band but also visible in the 48 Hz and 97 Hz band (harmonic). The temperature in the room was about 25° C when the measurement started. The switching pattern of the freezer is also seen in the graph for both sound and vibration.

3.1.7 Concluding case 1

Unfortunately it was not possible to test the theory of the domestic cooling device being the sound source causing all the trouble. The family did not want to spend more time and money to the investigation and was disappointed in the result. After all the measurements that had been done, the possible source seemed to be so common. They just did not believe it. Of course, if the logging measurements had been done sooner, time and money would have been saved but the family was very convinced of the involvement of the hospital. Furthermore in their experience the noise was always present. However it is known that ear and mind can be tuned to the sound so that it leaves an acoustic impression. You can even hear the sound when it is not there. The measurements showed that the noise was not always present despite the perception of the family. And again, the family found this hard to believe.

3.2 Case 2

This case is situated in a single home in an urban location. The family consists of 2 adults, man and wife. The woman is highly annoyed by the low frequency noise and suffers from sleeping problems. The man is aware of the noise but is able to sleep. He just wants his wife to be able to sleep again.

Opposite to their home a leisure centre with public indoor swimming pool is situated. Within a short distance (100 meters), several tall buildings are located.

In the first interview the family report that they are unable to put a finger on the sound source with certainty. They strongly suspect the indoor swimming pool because it has a lot of technical installations on the roof. They already complained to the local authorities about annoyance by the swimming pool. The authorities have carried out several sound measurements but since the review of noise in the legal way is done for the A-weighted sound level outside the home, it doesn't help with annoyance inside their home. The sound level outside their home was within the legal limits of the leisure centre.

The low frequency noise was not always present and sometimes louder than at other times. Therefore the following strategy was chosen:

1. manned sound measurements done by the family itself using a sound level meter and a portable DAT recorder to record the noise;
2. if something was found, additional unmanned logging measurements measuring the noise inside and outside the home simultaneously would be carried out.

3.2.1 Results of manned measurements

Using a B&K 2231 SLM and a Sony D10 portable DAT recorder, the family made several recordings on different places in their home. The results of the analysis of the DAT recordings is shown in figure 8.

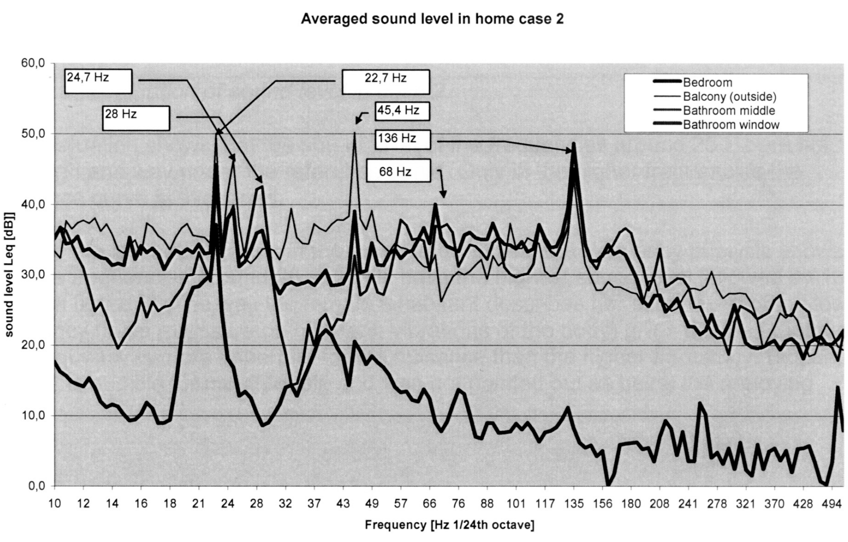

Figure 8 Results analysis DA T recordings.

The frequency spectrum shows several peaks:

- 22.7 Hz and the harmonics of 45.4, 68 and 136 Hz
- 24.7 Hz
- 28 Hz.

All locations show a peak at 22.7 Hz. The harmonics are not present on every location. The sound level at 136 Hz is pretty high. The measuring position outside on the balcony shows the same frequencies compared to the inside measurements. This gives a strong clue that the sound source might be outside the building.

Figure 9 shows the evaluation of the noise measured in the bedroom and the bathroom Both results are compared to the reference curve.

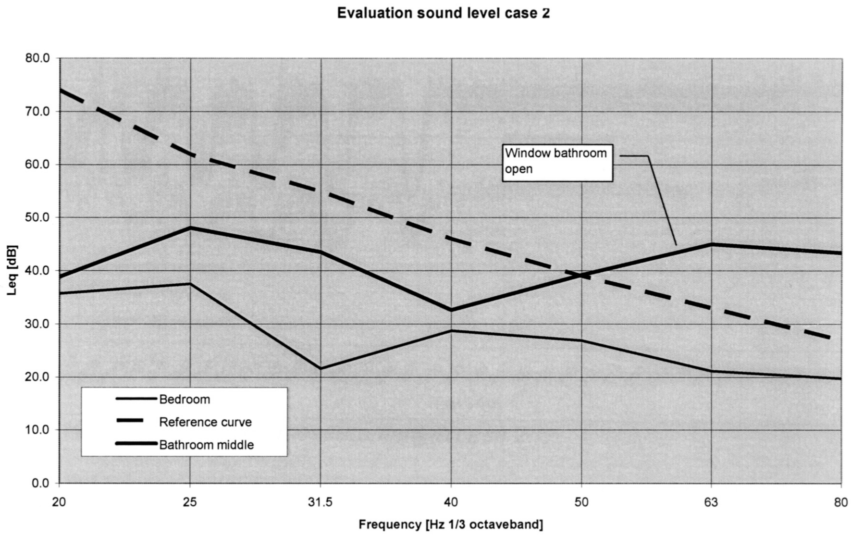

Figure 9 Evaluation of sound level in case 2.

The evaluation shows that the sound levels of the frequencies around 25 Hz are not very high and way under the reference curve. Only in the higher frequencies is the reference curve exceeded.

Despite the low sound levels in the lower frequencies, the frequency analysis shows that the frequencies around 20 to 25 Hz have the highest sound level followed by 136 Hz (see figure 8). The way the female inhabitant describes her experience of the low frequency noise (pressure on her ears, vibrations of the body) gives the idea that the low frequency is more important for the nuisance than the higher frequency. Besides, 136 Hz is audible for most people and was not pointed out as being the annoying sound.

3.2.2 Results of logging measurements

Due to the thought that the sound source is located outside the building, a 2 channel logging measurement was done. One B&K 4165 microphone was placed in the living room on a location where nuisance occurs. The second B&K 4165 microphone was located outside facing the leisure centre. The B&K 2144 was used to analyse and store the sound levels. The measurement was done the 16th of March 2005. The temperature during the night was between 9° and 5° C.

In the analysis of the measurement, the frequencies of 22.7 and 135 Hz were of interest. Figure 10 shows the result of the measurement for these frequencies. In the graph the sound level is plotted in time.

The sound source switches on and off in the beginning of the night. From about 3 o'clock in the morning it is continuously working. This pattern is visible in the 22.7 Hz inside the home and outside. The sound level outside is higher than inside. The frequency of 135 Hz outside follows the switching pattern. From this measurement it is concluded that the sound source is located outside the building. Although not shown in the graph because it would make the graph less clear, the same pattern was also found for 11.4 Hz. The sound level varies from 33 to 40 dB.

3.2.3 Finding the source outside

Since the 135 Hz band was well measurable outside and following the switching pattern of the 22.7 Hz, the idea was to use a directional microphone to find the source. The Sennheiser microphone MKH816T was used. From about 125 Hz this microphone has an opening angle in its sensitivity pattern from about 100°. This is usable to find the direction of the source. Therefore, three measurements had to be done to do a cross bearing. The microphone was attached to a 4 meter high tripod so it could be turned in different directions. The main direction of the sound source was determined by doing measurements over 360°. The direction giving the highest sound level is the main direction.

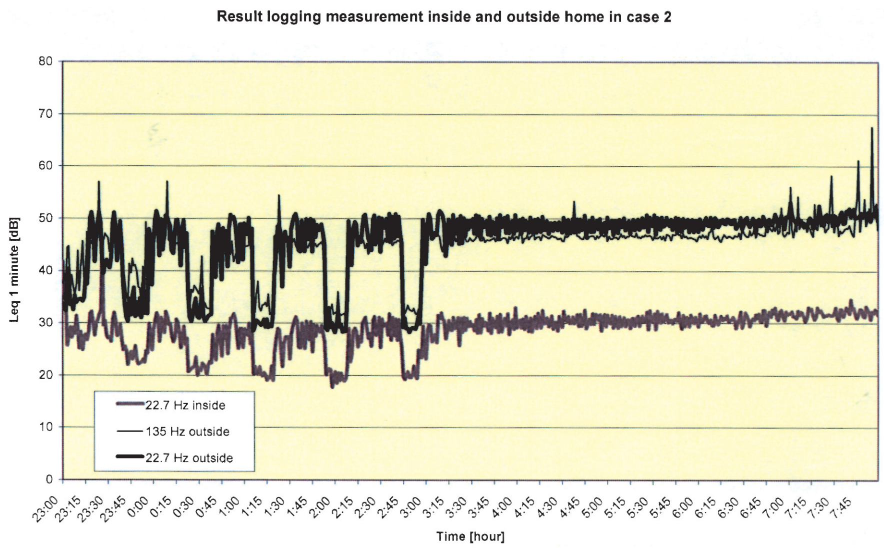

Figure 10 Result of logging measurement in case 2.

The measurements were carried out on May 10th 2005 between 03.00 and 05.00. Starting at the roof of the home, the direction of the sound level in the 135 Hz band was scanned by turning the microphone very slowly. The B&K 2144 analyzer was used measuring in "fast" so fluctuations in the sound level could be followed well. Figure 11 shows the three measurement points and the main direction found. The measurement in point 3 gave some trouble due to heavy traffic that started driving from 04.30.

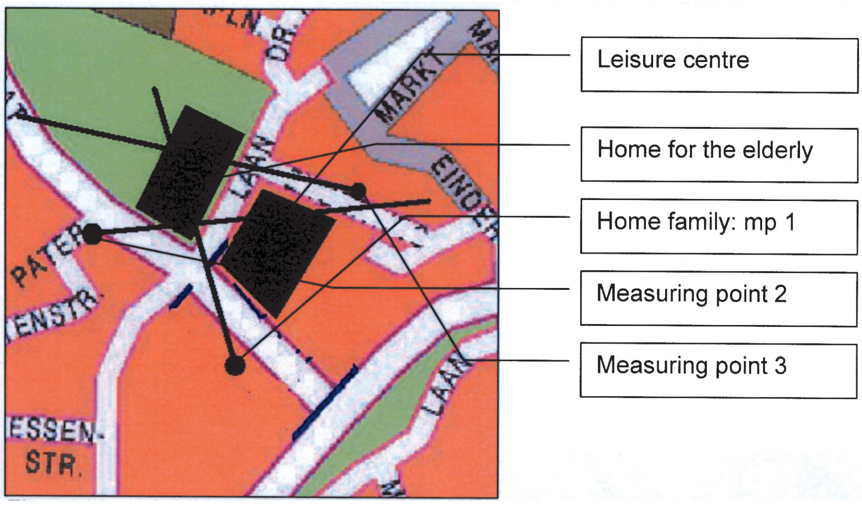

Figure 11 Main directions found by using directional microphone.

The Home of the elderly was found to be the source of the 135 Hz. A first brief inspection of the building from the outside, didn't reveal a possible sound source. The Home of the elderly has several technical installations but it was not possible to do any measurement from the outside.

Because the family knew some people involved in the management of the Home, they wanted to contact them and try to find the source themselves by switching installations on or off.

3.2.4 Conclusion case 2

Again, a case ends without definitive knowledge of the sound source. Again, money was the most important reason to stop the search. As far as known now, the burners of the heating system of the Home for the elderly have been replaced but the effect of this replacement is not known. The family have called in the help of the environmental department of the federal authorities because their help is for free. The use of the logging measurements was of great help to determine whether the sound source was inside or outside. Due to the relatively high frequency of 135 Hz, the use of a directional microphone was possible. Although the measuring results were not conclusive, a good idea of the possible sound source was obtained.

3.3 Case 3

Case 3 is situated in an apartment building in a town centre. The ground floor of the building is taken by shops and restaurants. On top of this floor, 4 floors containing apartments are situated. The apartment numbers 5 and 6 are situated on the first floor on top of an ice cream restaurant and a sandwich shop or lunchroom. The people living in these apartments complain about a constant humming noise. They suspect the ice cream restaurant or the sandwich shop due to the large cooling installations. But other shops with technical installations are located in the building and could be the source as well. In 2003 the installations of the ice cream restaurant and sandwich shop were turned off, but this did not result in a clear picture of the sound source. The inhabitants of the apartments think that not all the installations were turned off despite the words of the owner of the restaurant and shop. The inhabitants are represented by the housing association. The association agreed to pay for new sound measurements.

Because the inhabitants of the apartments did not want the owners of the shops to know that an investigation was carried out, unmanned logging measurements during the night for several nights were carried out. Two microphone positions were used: one in the bedroom and one outside a window. The goal of the measurement was to find out:

- is the source located in the building or outside?
- What frequencies are of interest?
- Are any switching patterns visible?

The measurement equipment used were two microphones B&K 4165 and the B&K analyzer 2144.

3.3.1 Results of the logging measurements

The measurements were carried out in apartment number 5. Figure 12 gives an overview for every night of the averaged A-weighted sound level in the bedroom and the measurements started at 23.00 and ended at 08.00.

Figure 12 shows that the average sound level in the bedroom is about 37 dB(A) which is unpleasantly high for a bedroom. It also shows that the sound level outside is about 45 dB(A). Due to the delivery of goods between 07.00 and 08.00 on Tuesday morning, the sound level for this night was relatively high compared to the other nights. If this night is left out, the averaged sound level outside is 42 dB(A) which is not uncommon for a city centre.

For every night a spectral analysis of the sound level was made. The spectra for each night were averaged to one spectrum. This spectrum gives a first overview of possible relevant frequencies. These frequencies were analysed later with their course in time. Figure 13 shows the result for the inside measurement.

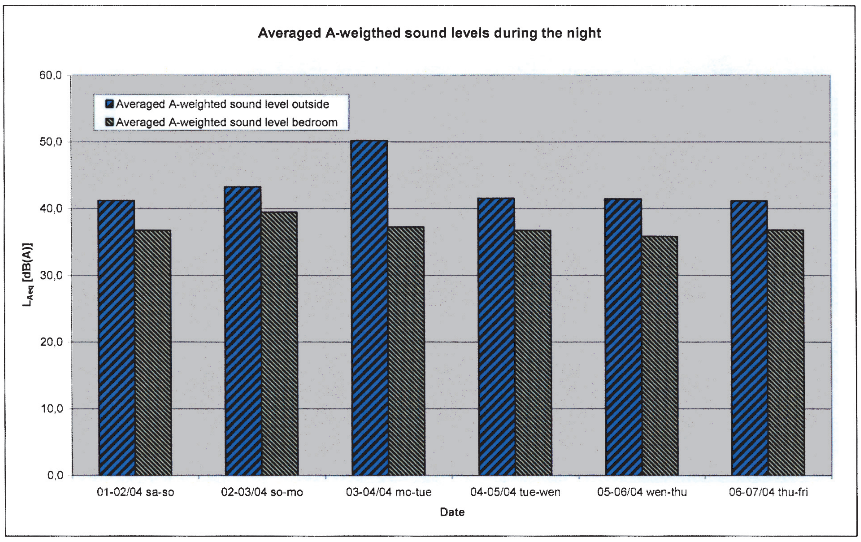

Figure 12 Averaged A-weighted sound levels per night.

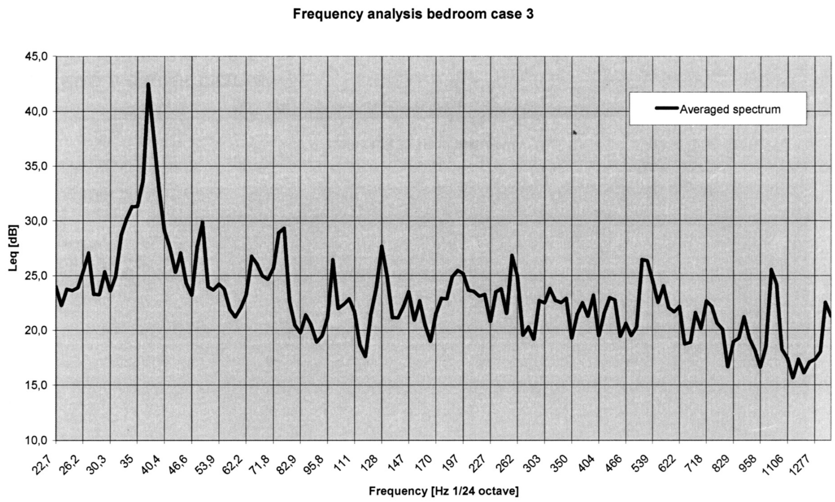

Figure 13 Averaged spectrum bedroom case 3.

A frequency of 37 Hz was found as a dominant frequency. The second harmonic at 74 Hz is visible as well. Furthermore the frequency of 48 Hz is visible as a peak.

The averaged sound level in the bedroom was evaluated according to the reference curve for low frequency noise. Figure 14 shows the result.

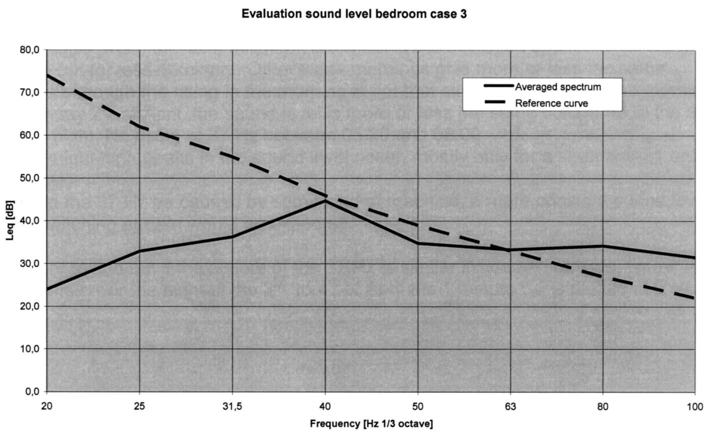

Figure 14 Evaluation of low frequency noise in bedroom case 3.

The dominant 37 Hz is part of the 40 Hz 1/3 octave band. Despite the rather high sound level, the reference curve is not exceeded. Only for the higher frequencies like 80 and 100 Hz (1 /3 octave band), is the reference curve exceeded.

Figure 15 shows the course of 37 Hz in time (1 minute L_{eq}) for two nights. Other nights give a similar picture.

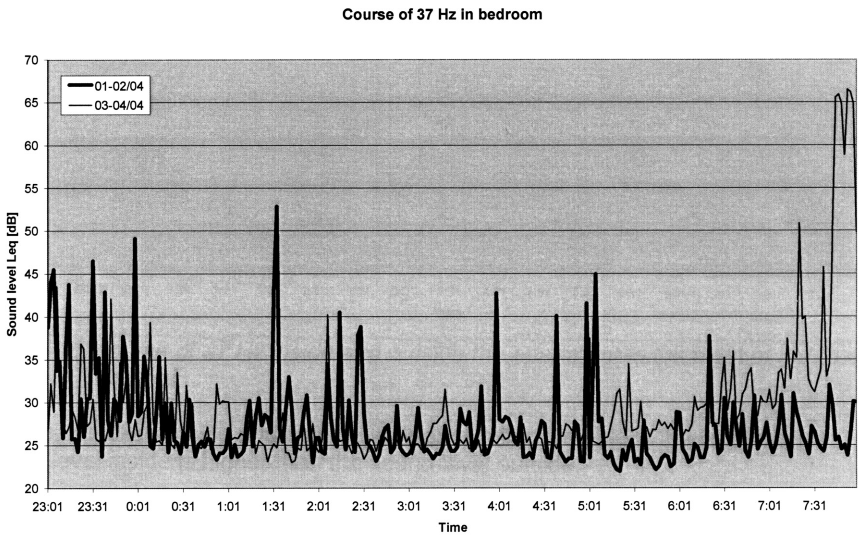

Figure 15 Course of 37 Hz in bedroom for 2 nights.

Figure 15 shows that there is no switching pattern in the 37 Hz band. From 23.00 to 0.30 hours the sound level declines. On Tuesday morning (3^{rd} - 4^{th} of April) from 05.30, it starts to rise again. From 07.30 it rises a lot, up to 65 dB. This causes the dominance of the 37 Hz. If this night is left out in the averaged spectrum, 37 Hz is still visible but far less dominant. Other week mornings give more or less the same course although the rising in the morning is not that strong. However, in the morning of Sunday 2^{nd} of April, the sound level is more or less the same compared to the rest of the night. No rising of 37 Hz between 05.30 and 08.00.

Every night high peaks in the sound level occur, mostly only for a short time (1 or 2 minutes).

Should the 37 Hz be caused by some kind of machine, a more constant sound level or a switching pattern would be expected.

In order to find out if the course of the 37 Hz is similar inside and outside, figure 16 is presented. For the night of the 3^{rd} to 4^{th} of April the 1 minute L_{eq} is plotted in time.

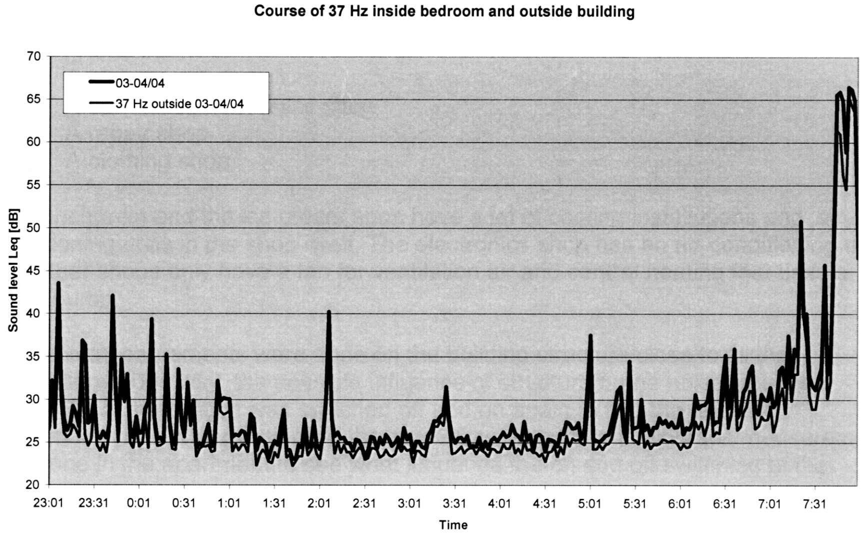

Figure 16 Course of 37 Hz inside and outside the apartment in the night of 3rd to 4th of April.

The sound levels inside and outside are very similar. Notable is the fact that the sound level inside is higher than the sound level outside.

3.3.2 Inside or outside?

The difference in A-weighted sound level between inside the apartment and outside is relatively small, about 5 to 8 dB. Normally a difference of about 15 dB is expected. The small difference can be caused by a sound source inside the building which, due to flanking or structure borne noise, causes extra noise. For this reason a simple test was done: listen to the walls in the bedroom by putting one's ear directly against the wall and yes: the sound of a technical installation was audible very well. This means that a sound source must be inside the building. However, it is not clear that this is the source of low frequency noise.

3.3.3 More measurements

In the building, about 24 apartments and 5 shops are housed all with their technical installations. Although the ice cream shop and the lunchroom have the most installations, especially cooling and freezing installations, an open mind should be kept for other sound sources in the building. Possible other suspects are heating pumps or ventilation systems. Switching off and on all these possible sources is a way to determine the sound source or sources but a lot of work. Before the switching test can be done, an inventory of all the sound sources has to be made. This was proposed to the housing association who gave permission to do the investigation.

Since the residents of the apartments were convinced that one of the installations of the ice cream shop and lunchroom was responsible for the nuisance, the investigation was started with these installations. The technical installations of the apartments and the building itself were not investigated at this stage.

On the 26th of October 2006 the installations in five shops were investigated. The shops were:

- A lunchroom
- An ice cream shop
- A consumer electronics shop
- A repair shop
- A clothing shop

The lunchroom and the ice cream shop have a lot of cooling installations and air-conditioning units in the shop itself. The electronics shop has an air-conditioning unit. The other shops only have a fan for ventilation air and central heating that uses a water pump.

Vibration measurements were done on the building structure close to all the installations. This way, the possible influence of structure borne noise would be found. Every installation was switched off and on again to find the relevant frequencies of that installation. At the same time a sound and vibration measurement was done in the apartment to see what influence the on and off switching of the installation had.

Table I shows the result of the source measurements. For every installation 5 relevant frequencies are given (if available). The table also shows if the installation is working in the night.

Only three installations have a relevant frequency around 37 Hz. Two installations are switched off during the night by the use of a timer. Only the "freezer middle" possibly switches on and off during the night. During the time the measurements were done, the ice cream shop was closed. The freezers were in use but there was not much ice cream inside them and the freezers were hardly opened. In fact, in order to be able to measure the freezers, the set point temperature had to be lowered a lot to switch the freezers on. With normal temperature set point, the freezer will hardly switch on.

Based on these measurements, the first conclusion was that these freezers, or the other sound sources, are not responsible for the annoyance.

Table 1.
Results source vibration measurements

Shop	Installation	Freq 1 [Hz]	Freq2 [Hz]	Freq 3 [Hz]	Freq 4 [Hz]	Freq 5 [Hz]	Working in night?
Ice cream	Small freezer	48	49				On demand
	Freezer left	98.6	48	35	34		On demand
	Freezer middle	33-37	48	21.4	98.6	143	On demand
	Freezer right	43.4	48	98.6			On demand
	Airco unit	48	23.4	98.6			From 06:00
	Airco condenser	48	143	35			From 06:00
	Freezer selling	46.6	38	93	139	128	No
	Fridge drinks	21	98.6				On demand
	Compressor	98.6	48	143	40		No
	Cooling fan	38	44				No
Lunchroom	Freezer cel	48	98.6	95.8			On demand
	Fridge	98.6	143				On demand
Electronics	Airco outside	48-49.6	95.8-98.6	147		No	
	Airco inside	12					No
Repair shop	Ventilation fan						Not in working order
Clothing	Ventilation fan	135					No

During the source measurements, a vibration measurement was done on the wall of the apartment. Since a lot of sources have relevant frequencies around 48 and 99 Hz, the influence of these frequencies on the vibration level in the apartment was studied. A graph was plotted for these frequencies during the measurement period in the ice cream shop and the lunchroom because the inhabitants of the apartments thought these shops were responsible for the annoyance. The frequency of 37 Hz was also plotted in the graph.

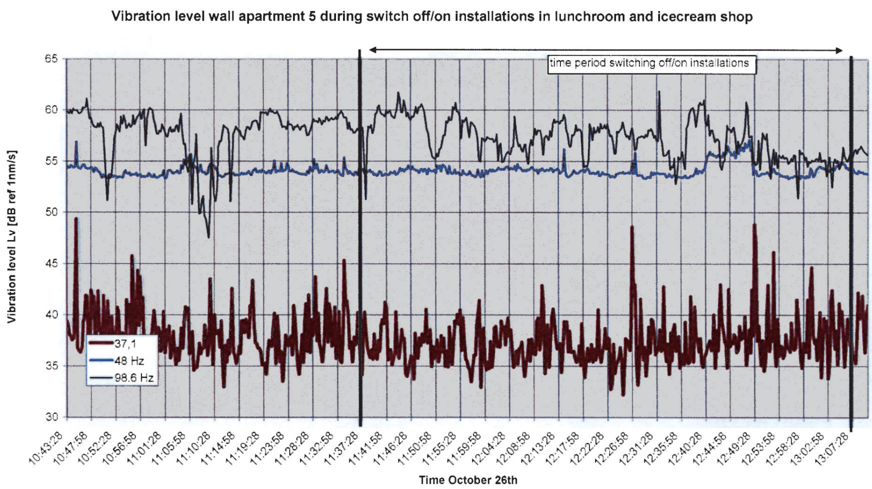

Figure 17 Time plot of relevant frequencies

From figure 17 it is clear that the installations from the lunchroom and ice cream shop are not relevant for the vibration level (and the sound level) in the apartment.

3.3.4 New developments

During 2007 the complaints about low frequency noise disappeared. It is not known what source was switched off. Possibly a technical installation for the building itself but it is also possible that a (small) installation in one of the other apartments was responsible for the annoyance. Since there are no more complaints, the housing association is not willing to spend more money on measurements although it is interesting to have results in a period without complaints.

4 CONCLUSION

Finding the source is not an easy job. Three cases and so far no definitive sound source but only possibilities. However, based on the experiences from these cases, the schedule in chapter 1 (see figure 1) is changed. The new schedule is presented in figure 18 and is now used as the measurement procedure for low frequency noise.

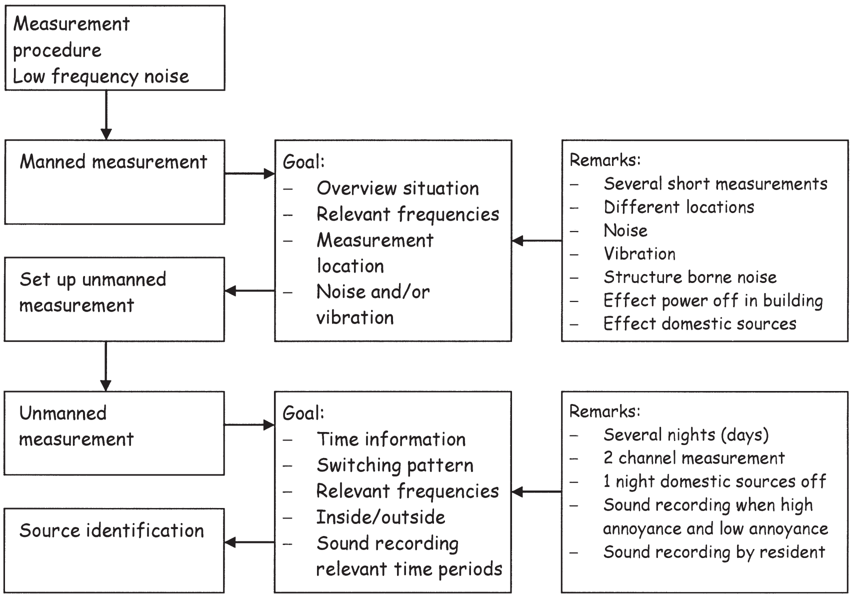

Figure 18 Procedure measurement low frequency noise

Manned and unmanned measurements are useful in order to identify the source of low frequency noise. The manned measurement is used to get a first overview of the situation and help decide what parameters and location(s) should be used in the unmanned measurements. Of course, when the results of the manned measurements already point out the source, unmanned measurements are not necessary anymore. But the three cases prove that most of the time it is not that simple. The unmanned measurements are used to get more information about the noise over a longer period of time especially when the annoyance varies in time. Recording the sound is very helpful. If the recording is made in two situations, first when the annoying sound level is high and later when the sound level is low, it is possible to compare both situations. Furthermore the recording can be used for more detailed analysis.

In this paper several techniques are described to measure and identify the source of low frequency noise. But another important condition that has to be met to be successful in the search for the source, is the availability of time and of course money. If there are many possible sound sources, it takes a lot of work to reduce the possibilities. If an individual has to pay for these investigations, they will not (or are not able to) go as far as could be wished to find the source. Due to the lack of legal regulations, the government has not many possibilities to invest in investigations to find the source. Hence, the source is often not found and the investigation is stopped half way. The nuisance still exists.

REFERENCES

[1] "Kijk" (Dutch monthly magazine about popular science), edition March 2006, pages 32-36.

[2] "Bromtoon in Gouda nog onvindbaar", ("Hum in Gouda still not found"), item on the Website Geluidnieuws (Dutch website about noise and vibrations), http://www.geluidnieuws.nl/2006/iuni2006/aouda.html, June 2006.

[3] "Richtlijn Laagfrequent Geluid" (Guideline Low Frequency Noise),1999, in Dutch, Nederlandse Stichting Geluidhinder, (Dutch Foundation Noise Nuisance), www.nsg.nl.