LONDON SOUTH BANK UNIVERSITY

SCHOOL OF ENGINEERING SYSTEMS AND DESIGN

AN ACOUSTIC EVALUATION OF A LONDON NIGHTCLUB – THE DOGSTAR

MSc Environmental and Architectural Acoustics

MSc Thesis

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Abstract

"The Dogstar" is a busy London nightclub that poses many questions of an acoustic nature. This documents focuses itself on three central areas of acoustic assessment.

By measurement of the daily noise exposure of employees using noise badges and a sound level metre, it concludes that the bar staff are exposed to levels of noise that exceed the upper exposure limits as determined by the current and future "Noise at Work Directives".

An acoustic assessment of the space in terms of the PA systems effective output frequency response and sound localisation was undertaken. Based on a series of broadband and 1/3 octave band measurements this assessment helped to develop an equalisation strategy that could be used to balance the effective frequency response of the PA system.

For purposes of planning and acoustic optimisation, an acoustic model of the nightclub using Catt-Acoustic was built and through comparison of a series of measured and predicted reverberation times, the accuracy of the model was assessed. Although high level of accuracy were not attained the resultant data was fully assessed and the cause of error quantified.

CONTENTS

Section 1 – INTRODUCTION & BACKGROUND

1.1 - The Dogstar

The Dogstar has been around for many years and is one of the most well known and popular bar/nightclubs in the Brixton area. It has always had a reputation as a great DJ venue and over the last 10 years some of the biggest names in the business have made it their home. Although the DJs provide most of the venue's entertainment it is sometimes used for live music events, theatre, comedy and poetry readings. The venue consists of three floors and usually plays different styles of music on each night of the week. For additional information about the Dogstar, its history and current events visit their website at: **www.thedogstar.com**

Figure 1.1 – Photograph of the Dogstar

1.2 - Aims

One of the central aims of the thesis was to provide an internal acoustic assessment of a busy London club, namely the Dogstar. This would include an evaluation of the noise exposure of employees in relation to the relevant Directives. It would also include an evaluation of the sound level and frequency distribution throughout the club in terms of audible fidelity and the specific requirements of sound localisation. An additional aim of the thesis was to create an equalisation strategy from this sound distribution assessment that could be used to improve the nightclub's acoustics. The final aim of the thesis was to build an acoustic model of the night club in the software application Catt-Acoustic and evaluate its relative prediction accuracy.

1.3 - Outline

The main body of the thesis will be broken up into five main sections. The first will provide background theory, technical information and the literature review. The second will evaluate the noise exposure of the employees in relation to the relevant Directives. The third will assess the nightclub's sound distribution and provide an equalisation strategy. The fourth will discuss the modelling process and evaluate its relative accuracy. The fifth will provide general conclusions, discuss further possible work and provide the references and appendixes.

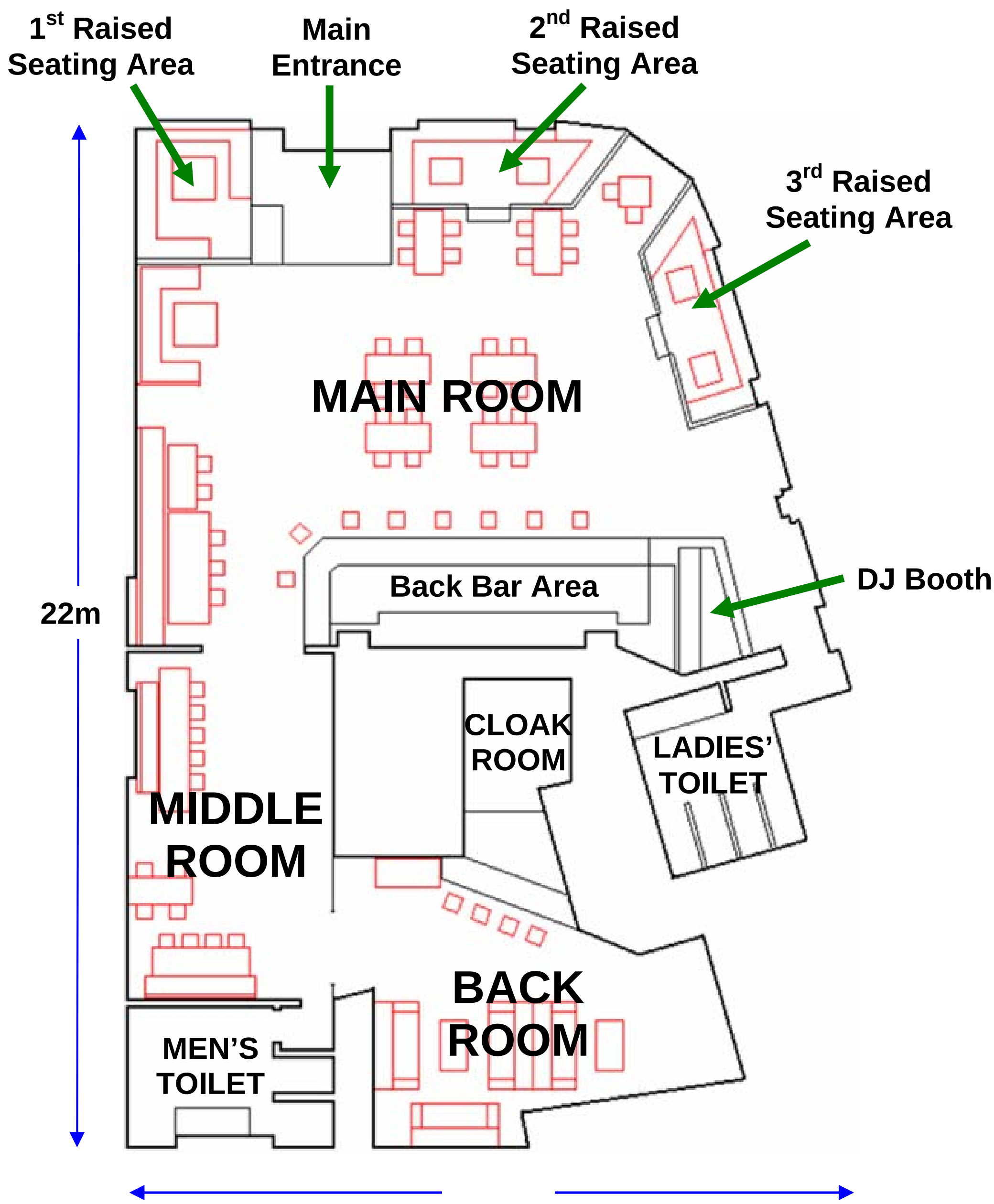
1.4 - Theoretical and Technical Background

This section of the document will provide information about the club layout and the PA system that will be referred to in the following sections of the document. It will also provide a glossary of the acoustic terms used throughout the document for readers with less knowledge of acoustics.

Club Layout

This section provides a plan diagram of the club layout displaying the various areas and basic geometry. Detailed sketches of the clubs geometry used for the modelling process have been included in the appendix *(Pages 111 - 120)*. The areas coloured red represent the seating areas, i.e. tables, chairs, benches, sofas, etc.

Figure 1.2 – Plan diagram of the club layout



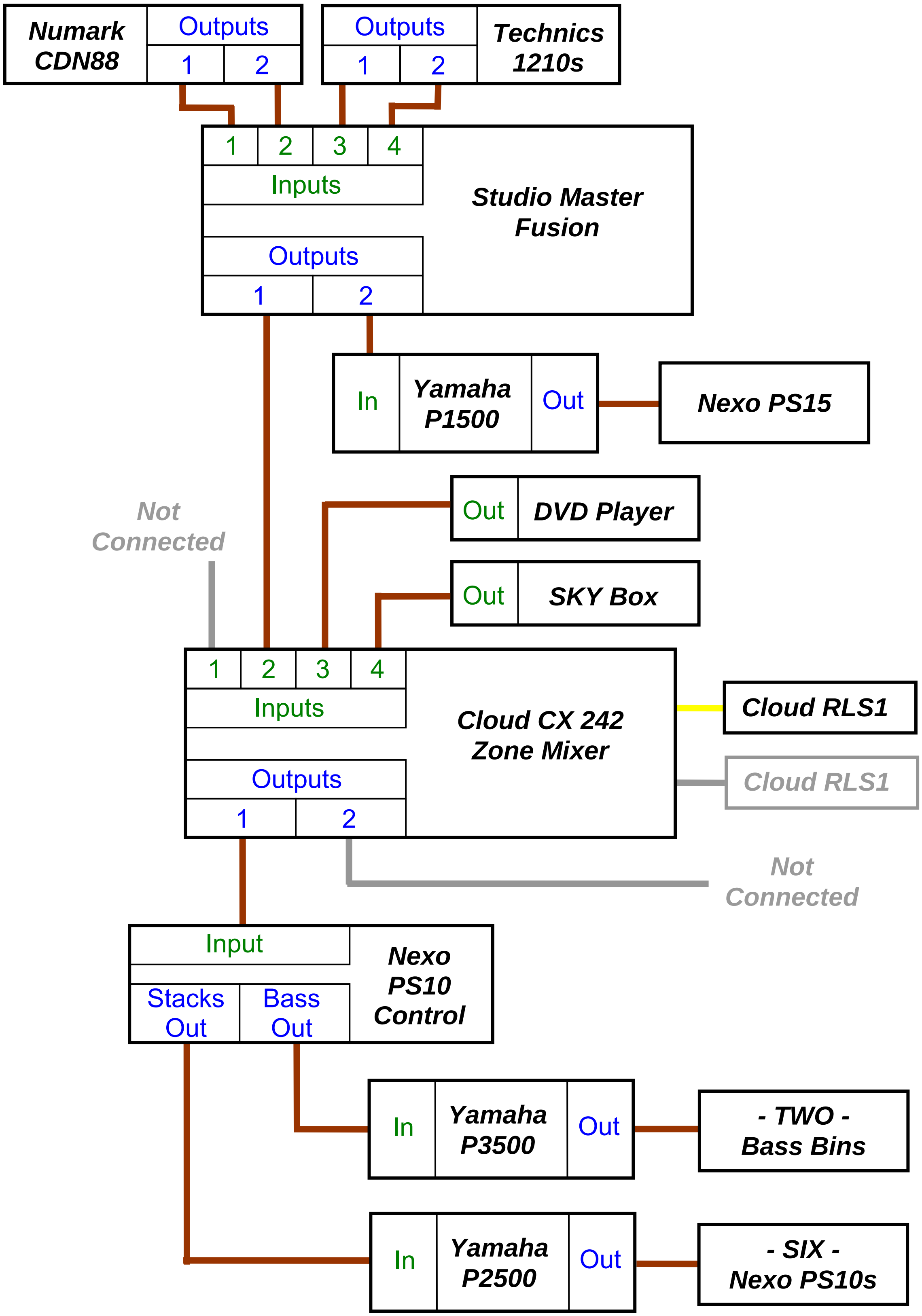
The PA System

This section provides a block diagram explaining how all the component parts of the PA system are connected together and a table providing a brief description of the functionality and location of each.

Table 1.1 – Information about the component parts of the PA system

OBJECT	LOCATION	FUNCTION DESCRIPTION
Numark CDN88	*DJ Booth*	The CD players used by the DJ.
Technics 1210s	*DJ Booth*	The record decks used by the DJ.
Studio Master Fusion	*DJ Booth*	The mixing desk used by the DJ.
Cloud CX242 Zone Mixer	*Amp Room*	A mixer used to select witch inputs are fed To the PA and to control the output level .
Cloud RLS1	*Behind Bar*	A remote control devise for the CX242.
Nexo PS10 Control	*Amp Room*	A loudspeaker cross-over unit and optimisation devise. This splits a signal Into the frequency spectrums suitable for the different types of loud speaker.
Yamaha P150	*Amp Room*	The amplifier used to power the DJ monitor.
Yamaha P250	*Amp Room*	The amplifier used to power the stack speakers *(Nexo PS10s).*
Yamaha P350	*Amp Room*	The amplifier used to power the bass bins.
Two Bass Bins	*Club Area*	The two bass bin speakers used to transmit bass frequencies.
Six Nexo PS10s	*Club Area*	The six stack speakers used to transmit the mid and high frequencies.
Nexo PS15	*DJ Booth*	The DJ monitor speaker.
DVD Player	*Office*	Used to play DVDs.
SKY Box	*Office*	Used to select TV station.

Figure 1.3 – Connections between the component parts of the PA system



Glossary of acoustic terms

Sound Level A subjective measure of sound expressed in decibels as a comparison corresponding to familiar sounds experienced in a variety of situations.

dB Decibel: A unit for measuring sound that is not absolute but a ratio between a measured quantity and an agreed reference level.

SPL Sound Pressure Level: An important measure of sound loudness, the level is calculated in decibels by 20 times the logarithm to the base 10 of the ratio of the measured sound pressure level and a reference level of 20μPa corresponding to the threshold of hearing.

(A) weighting A frequency dependant correction which weights sound to correlate with the sensitivity of the human ear to sounds at different frequencies.

(C) weighting Similar to A-weighting but is with a different weighting strategy more sensitive to bass frequencies.

$L_{eq,T}$ The continuous equivalent noise level of a time varying noise: This is the sound pressure level of a steady sound that has, over the time period T, the same amount sound energy as the time varying noise. Unit of measurement - dB

$L_{Aeq,T}$ The continuous equivalent noise level of a time varying noise: This is the sound pressure level in dBA of a steady sound that has, over the time period T, the same amount A-weighted sound energy as the time varying noise. Unit of measurement - dBA

P_{Cpeak} C-weighted Peak Sound Pressure: The greatest instantaneous C-weighted sound pressure measured within a specified time interval. Unit of measurement - Pascal (Pa)

$L_{EP,d}$ or $L_{EX,8h}$ The daily personal noise exposure of a worker: The continuous A-weighed sound pressure level that would provide an equal amount of sound energy over an eight hour period independently of the actual exposure period. Unit of measurement – dBA

$L_{EP,w}$ or $\overline{L}_{EX,8h}$ The weekly average of the personal noise exposure: The continuous A-weighed sound pressure level that would provide an equal amount of sound energy over an forty hour period independently of the actual exposure period. Unit of measurement – dBA

RT Reverberation Time: The persistence of sound in a closed space after a noise source has been cut-of. The reverberation time is defined as the time in seconds necessary for the sound pressure level to decrees by 60 dB after the source has been cut-off and it is a function of frequency.

RT_{15} & RT_{30} These are also definitions of the time in second necessary for the sound pressure level to decrees by 60 dB after the source has been cut-off. However, these measurements are taken at 20dB and 30dB and normalised up to 60dB using the slope of a straight line approximation.

EDT Early Decay Time: The EDT is very similar to the RT but the decay time is measured between 0dB to -10dB of the decay curve and normalised up to 60dB using the slope of a straight line approximation. Because there is no 5dB bias as used for RT measurement, the EDT represents the time taken for the early reflections to reach the receiver.

D_{50} and D_{80} Definition: This is one of a group of parameters that measures the balance between early to late arriving sound energy and in calculated from the impulse response at a particular receiver position. Usually the early time limits are set at 50ms or 80ms depending on whether the results are intended to quantify conditions related to speech or music respectively.

STI Speech Transmission Index: This parameter is used for the purposes of rating the quality of speech transmission with respect to intelligibility in different listening spaces and is assigned one of six specific quality ratings.

1.5 – Literature Review

Because of the experimental nature and scope of this thesis there are very few literary documents that are of any relevance. However, Section two deals with sound exposure to workers and as such both the soon to be out dated Noise at Work Regulations Directive 86/188/EEC[1] and the new Physical Agents Directive 2003/10/EC[2] will be reviewed. However, sections three and four are entirely experimental and although there are many research works, published guidelines and criteria relating to entertainment noise, none of these relate to the areas perused in the thesis. One of the purposes of a literature review is to summarise and review the various literature that has helped to guide and shape the forthcoming work. Because no literature has been used for this purpose no additional documents will be reviewed.

Directive 86/188/EEC - The Noise At Work Regulations 1989

This European Directive became a statutory instrument on the 1st of January 1990. At this point it became "The Noise At Work Regulations 1989[(1)]" The central aim of this Directive is to protect workers from damage to their hearing. The directive was applied to all workers with the exception of those involved with sea and air transport.

It states that noise experienced at work must be assessed and where necessary measured in order to identify under which specific provisions of the directive apply.

The directive utilises an upper and lower set of exposure action values to which the specific provisions are applied.

A) Lower exposure action values: Where the worker is exposed to an $L_{EP,d}$ that exceed 85dBA or a P_{Cpeak} that exceeds 200Pa.

B) Upper exposure action values: Where the worker is exposed to an $L_{EP,d}$ that exceed 90dBA or a P_{Cpeak} that exceeds 200Pa.

If after assessment, the noise exposure exceeds these exposure levels it is necessary for a series of provisions to be made. Some of the most important of which are given below.

Lower exposure action values:

- The employer must provide information and where relevant, training about the dangers of noise exposure.

- Workers have the right to hearing checks / audiometric testing by or under the responsibility of a doctor and the right to the results.

- Hearing protection must be made available to the staff

Upper exposure action values:

- The employer must ensure that hearing protection in worn by employees.
- Where reasonably practicable, signs must be put up warning of the dangers. In addition, these areas must be delimited with access restricted.
- Employers must draw up and apply a program of control measures designed to reduce as far as reasonably practical the workers noise exposure.

The Directive also makes provisions for the average weekly noise exposure ($L_{EP,W}$) of a worker. This is derived from the time-weighted average of the noise exposure levels over five eight hour working days. It states that if there is significant variation in the daily noise exposure then under exceptional circumstances, certain derogations from the action value provisions can be made. However, these derogations can only be made if the average weekly noise exposure complies with these values.

Directive 2003/10/EC - The Control of Noise at Work Regulations 2005

This new European Directive was adopted in December 2002 and was designed to repeal the old Directive 86/188/EEC. It will become a statutory instrument on the 6th of April 2006 and at this point will become "The Control of Noise at Work Regulations 2005[(2)]". However, an additional transitional period of five years for personnel on shipping vessels and two years for music and entertainment sectors will be granted. This means that until the 6th of April 2008, all clubs and pubs will still be bound by The Noise At Work Regulations 1989.

Because this new Directive has been designed to directly supersede the old Directive (86/188/EEC), much of its content is very similar. To avoid repeating the information given in the previous review only the significant differences between these Directives will be discussed.

The central difference between these Directives is that the two exposure action values have been reduced and a new exposure limit value introduced. The new exposure limit values are used as the absolute maximum levels a worker can be exposed to after any attenuation provided by ear protectors has been accounted for. The action values must not take account of the attenuation from such protection. The new Directive has directly replaced the old $L_{EP,d}$ with $L_{EX,8}$ (although the formulae for both are identical) and are given on the folowing page.

> ***A) Lower exposure action values:*** Where the worker is exposed to an $L_{EX,8}$ that exceeds 80dBA, or a P_{Cpeak} that exceeds 112Pa (alternatively a L_{Cpeak} that exceeds 135dBC).

> ***B) Upper exposure action values:*** Where the worker is exposed to an $L_{EX,8}$ that exceeds 85dBA or a P_{Cpeak} that exceeds 140Pa (alternatively a L_{Cpeak} that exceeds 137dBC).

> ***C) Exposure limit value:*** Where the worker is exposed to an $L_{EX,8}$ that exceeds 87dBA or a P_{Cpeak} that exceeds 200Pa (alternatively a L_{Cpeak} that exceeds 140dBC).

This Directive again makes provisions for a weekly noise exposure level when there is significant variation in the daily noise exposure providing it does not exceed the limit values. However, it does not make the same derogations made in the old Directive. The new Directive has again directly replased the old $L_{EP,w}$ with $\overline{L}_{EX,8}$ (although the formulae for both are identical).

An additional alteration of relative significance is a more stringent requirement for the use of warning signs around areas were the sound levels exceed the upper exposure values. The wording in this context has changed from, “where reasonably practicable”, to “where technically feasible”.

Section 2 - NOISE EXPOSURE

2.1 - Introduction

The central aim of this section is to ascertain what noise levels the bar staff are being exposed to, and to establish whether these levels comply with the regulations set out in the current and future "Noise at Work Directives" discussed in the literature review *(see pages 13 to 17)*. For continuity with these Directives the parameters analysed were C-weighted peak sound pressure (P_{Cpeak}), daily noise exposure limit ($L_{EP,d}$ / $L_{EX,8h}$) and weekly noise exposure limit ($L_{EP,w}$ / $\overline{L}_{EX,8h}$).

In obtaining these results, bar staff were fitted with noise badges and a sound level meter (SLM) was used to measure the levels behind the bar at regular intervals. These measurements were taken for the duration of their shifts throughout a full working week. At the time of this experiment the business was operating a six day week closing on a Monday. A timetable for the opening hours is given below.

Table 2.1 – Dogstar opening hours

DAY	Open	Close
Monday	-	-
Tuesday	*4pm*	*2am*
Wednesday	*4pm*	*2am*
Thursday	*4pm*	*2am*
Friday	*4pm*	*4am*
Saturday	*12 noon*	*4am*
Sunday	*12 noon*	*2am*

The business operates with a flexible shift structure where the duration and quantity of shifts varies greatly from week to week. Because of the long opening hours each working day is usually split up into day and night time shifts. Typical examples of these shift patterns are given below.

Table 2.1 – Typical examples of shift patterns

	Tuesday to Thursday	Friday	Saturday	Sunday
Day shift	*3pm to 7pm*	*3pm to 8pm*	*11am to 7pm*	*11am to 7pm*
Night shift	*7pm to 3am*	*8pm to 5am*	*7pm to 5am*	*7pm to 3am*

It should be stressed that although typical, the duration of a shift is regularly both extended and reduced. What is relatively consistent is that members of the day and night time teams tend to remain in there shift groups and rarely interchange within a working week.

Because of time constraints, equipment availability and relative acoustic interest, only the noise exposure of the night time teams has been analysed. The underlying reason for the choice of shift analysis is because the night time staff are exposed to much greater sound levels due to the nature of the business. For the remainder of this document, all reference to the days worked and shift patterns will refer to the night time shifts.

On Tuesdays, Wednesdays, Thursdays and Sundays, the bar usually employs two to three staff members and on Fridays and Saturdays, five or six staff are employed. Because on Fridays and Saturdays more staff are required than in the week, many of the staff work on a part time basis. The full time staff tend to work five shifts a week including the busy Friday and Saturdays with two nights off including the Monday. The part-time staff usually work two or three shifts in a week. These include, the Friday and Saturday and a shift during the week covering one of the full-timers nights off.

Because only two noise badges were available, it was only possible to monitor the exposure levels of two members of staff at any one time. Due to the possibility of an inconsistency between the daily exposure patterns, the same two full-time staff members were fitted with the noise badges whenever possible. In this manner, a weekly noise exposure limit calculation would reflect the true noise exposure of a single individual.

The noise badge measurements and SLM measurements were taken over six days from Tuesday the 15th, to Sunday the 20th of November 2005. Over this period, the two full time staff members (Subject A and Subject B) selected for analysis were rotaed on to work the five shift periods as described in *Table 2.3*. On there days off, an additional staff member was randomly selected for analysis (Subject C). Because only the specific shift exposure of this third subject was of relevance, continuity between specific subjects was disregarded.

Table 2.3 – Shift rota for the subjects across the week

	Subject A	**Subject B**	**Subject C**
Tuesday	*7pm - 2:30am*	*8pm - 2:30am*	-
Wednesday	*7pm - 2:30am*	*Off*	*8:30am - 2:30pm*
Thursday	*7pm - 2:30am*	*8pm - 2:30am*	-
Friday	*7pm - 4:30am*	*8pm - 4:30am*	-
Saturday	*7pm - 4:30am*	*8pm - 4:30am*	-
Sunday	*Off*	*8pm - 2:30am*	*8:30am - 2:30pm*

2.1 - Instrumentation

Two Noise Badges – 707 Larson Davies. *Serial numbers 14014506 & 14014489*

Sound level meter – Bruel & Kjaer Type 2231. *Serial number - 1401506*

Microphone calibrator. Cirrus CRLS11D. *Serial number 011932*

Lap top computer – Dell Inspiron 8600 *Serial number – X08 73061*

Noise Badge software – Larson Davis - LD 705Win. *Version 2.7*

2.3 - Method and Procedure

This section of the report will be broken down in to a sequential step by step account of how and why the experimental methods and procedures were carried out. The procedures discussed in this section were repeated for both noise badges, and the SLM on each of the six days described previously.

Step 1. A new set of batteries were fitted in to the noise badge and the SLM was calibrated.

It should be noted that it was not possible to calibrate the noise badges. The reason for this is because the noise badges require a specialised calibration devise that was not available from the LSBU. One of the main reasons for taking the SLM readings was due to inability to properly calibrate. By comparing the resultant noise badge data with the properly calibrated SLM data, it was possible to validate (at least partially) the data collected from the noise badges.

It was necessary to fit new batteries in the noise badges on each run because of the length of operation. Because the SLM was only used for a short period of each hour, the battery life could be constantly monitored and batteries replaced when required.

Step 2. As soon as a subject arrived for work a noise badge was attached.

To accomplish this the main body of the badge was clipped on to the belt or waist band of the subjects clothing. The microphone and connecting wire was then fed under the shirt/t-shirt and attached to the neck line or collar of the subject's top. The microphone was positioned so that it was outside the clothing and as high up the body as possible. In this way the signal would not be muffled by the clothing and the microphone would be as near to the subjects ears as possible.

Step 3. The noise badge was connected to the computer whilst attached to the subject, configured and activated. They were then disconnected from the computer and the subjects began their shifts.

Before the noise badges can be activated it's necessary to configure a series of parameters. The parameter options and configurations made for each of the record periods are given below.

Table 2.4 – Noise Badge parameter options and configurations

Option	Choice	Configuration made
RMS Weighting	*A or C*	*A*
Peak Weighting	*C or U*	*C*
Detector Setting	*Slow or Fast*	*Fast*
Time History Sample Interval	*1 to 255 Seconds*	*60 Seconds*

The RMS A-weighting and the Peak C-weighting was selected in accordance with the Directives. The detector setting was set to fast so that any transient signals would be registered and incorporated in to the resultant L_{Aeq} and P_{Cpeak} values.

The Noise Badge operates by recording the maximum P_{Cpeak} and L_{Aeq} levels over a specified sample period for the duration of the record period. By selecting 60 seconds for the sample interval the resultant data would provide minute by minute accounts of the subjects noise exposure. In addition to these configurations, when the noise badge is activated, the internal clock is synchronised to the computers.

> **Step 4**. After the first subject began their shift a two minute L_{Aeq} measurement was taken with the SLM at two different positions behind the bar every hour.

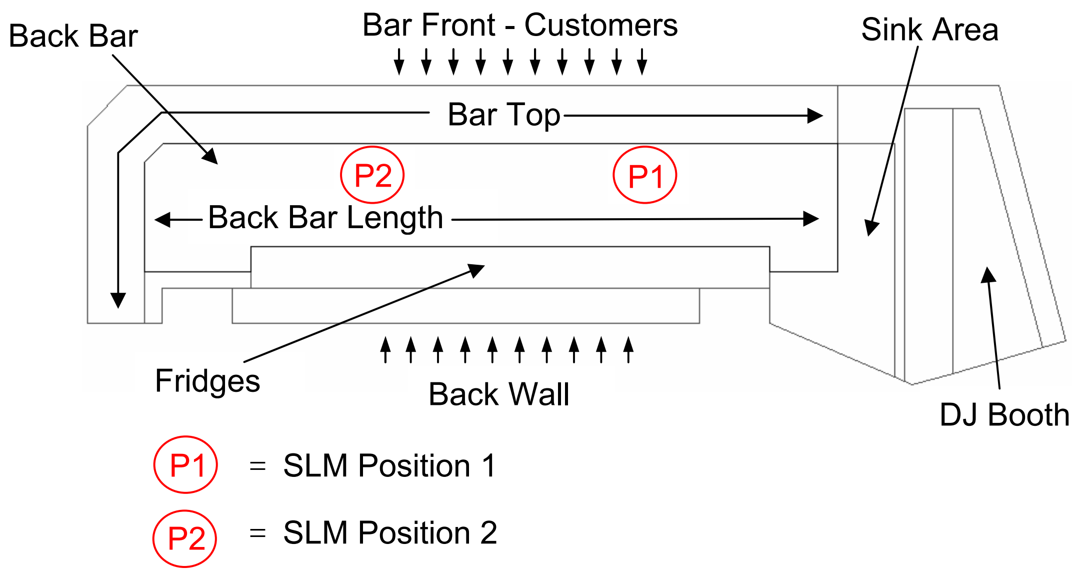
Because on most occasions it is extremely hectic behind the bar, a person standing in the centre taking a SLM reading is a hindrance to the staff. It is for this reason that a two minute L_{Aeq} period was selected. It was decided that this was the maximum period that would be accepted with the support of the management and staff.

The majority of a subjects shift period is spent behind the bar although when necessary, they are required to circle the club picking up glasses and emptying ashtrays. Although this glass collecting period is comparatively brief the sound exposure varies at different positions within the club. An evaluation of this varying sound exposure at different positions in analysed in Section Three.

For this reason, it would have been of interest to measure sound levels at positions along the likely glass collection route. However, it was decided after a brief trial run that measurements using the SLM during opening hours anywhere other than behind the bar were impractical. This was mainly due to the customers inebriated interest and tendency to either tap, or shout into the SLM.

The SLM measurements were taken at approximately ten minutes past each hour. An exact start period or exact position for either measurement was impractical because of the unpredictable and chaotic environment behind the bar. A scale diagram of the bar and approximate positions in which the measurements were taken are described below.

Figure 2.1 – Diagram of the bar and Approximate L_{Aeq} measurement positions



The approximate position of P1 was at two thirds of the back bar length from left to right. The approximate position of P2 was at one third of the back bar length from left to right.

For both measurements the SLM was held at approximate ear height (1.5m) towards the front of the back bar area and angled to face the customers.

> **Step 5**. Whilst the subject worked through there shifts they were monitored when ever possible to insure that the badges were not tampered with, removed or subjected to unrealistic exposure.

Because the noise badges and microphones were visible there were a few occasions where inebriated and over over-inquisitive customers gave the impression of wanting to grab or shout into the devices. This was avoided by being at hand to explain the purpose of the experiment.

Step 6. At the end of the subject's shift the noise badges were re-connected to the computer and instructed to end the recording process.

Step 7. The data from within the noise badge was downloaded on to the computer and saved as a database record within the software.

Once the data had been downloaded into the computer and saved as a database record, it is possible to manipulate the data in a multitude of ways. However, for the purposes of this experiment the only data manipulation required was to set an $L_{EX,8h}$ / $L_{EP,d}$ eight hour criterion duration. By doing this the software automatically calculates the $L_{EX,8h}$ / $L_{EP,d}$ value from the total L_{Aeq} of the record period.

Step 8. The database record was then exported in to a Microsoft Excel compatible file format.

The relevant data that was exported consisted of: All the individual P_{Cpeak} and L_{Aeq} levels for each of the 60 second sample periods. The complete L_{Aeq} of the entire shift duration. The greatest individual P_{Cpeak} measured during the shift duration. The calculated $L_{EX,8h}$ / $L_{EP,d}$ value for the entire shift. The start, end and duration times of the record period.

2.4 – Results

Although the noise badges' internal clocks were synchronised with the computer, they were not activated on the turn of a minute. For this reason where two or more sets of results share the same time scale, they have been shifted to the nearest minute. Therefore, It should be noted that although the sets of results appear to be perfectly in sync with one another, they could be out of sync by up to thirty seconds.

To calculate the $L_{EP,w}$ / $\overline{L}_{EX,8h}$ values provided in *Figure 2.9* the equation taken from The Control of Noise at Work Regulations 2005[2] given on the following page was utilised.

Formula for calculating the weekly personal noise exposure levels

Equation 2.1

$$L_{EP,w} / \overline{L}_{EX,8h} = 10\log_{10}\left[\frac{1}{5}\sum_{i=1}^{i=m} 10^{0.1\left(L_{EP,d} / L_{EX,8h}\right)_i}\right]$$

Where,

M = The number of working days on which a person is exposed to noise during the week

$(L_{EP,d} / L_{EX,8h})_i$ = The $(L_{EP,d} / L_{EX,8h})$ for working day i

Throughout the six day measurement period due to a variety of reasons, the three subjects actual shift hours did not correspond exactly to those on the rota (*Figure 2.3*). Given on the following page is a table of the actual shift start and end times and periods of duration.

Table 2.5 – Actual shift start and end times and periods of duration

		Start Time (hh:mm:ss)	End Time (hh:mm:ss)	Duration (hh:mm:ss)
Tuesday	***Subject A***	*19:18:41*	*02:44:09*	*07:25:28*
	Subject B	*21:50:11*	*02:41:48*	*04:51:37*
Wednesday	***Subject A***	*19:46:58*	*02:25:34*	*06:38:36*
	Subject C	*20:35:00*	*23:02:25*	*02:27:25*
Thursday	***Subject A***	*19:18:47*	*02:26:25*	*07:07:38*
	Subject B	*20:00:37*	*02:32:59*	*06:32:22*
Friday	***Subject A***	*19:23:42*	*04:41:00*	*09:17:18*
	Subject B	*20:17:38*	*04:44:45*	*08:27:07*
Saturday	***Subject A***	*19:24:06*	*04:12:42*	*08:48:36*
	Subject B	*20:03:07*	*04:22:51*	*08:19:44*
Sunday	***Subject C***	*20:51:51*	*01:18:02*	*04:26:11*
	Subject B	*20:16:35*	*01:19:50*	*05:03:15*

Figure 2.2 – Noise badge L_{Aeq}, P_{Cpeak} and SLM L_{Aeq} measurements taken during the Tuesday shift

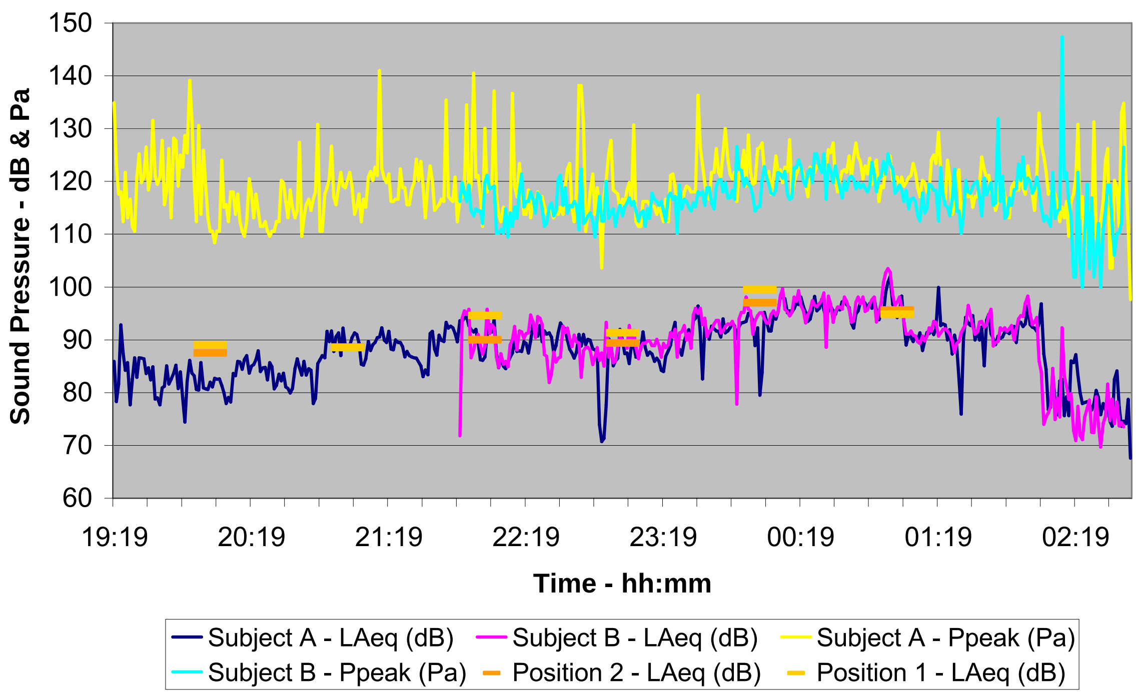


Figure 2.3 – Noise badge L_{Aeq}, P_{Cpeak} and SLM L_{Aeq} measurements taken during the Wednesday shift

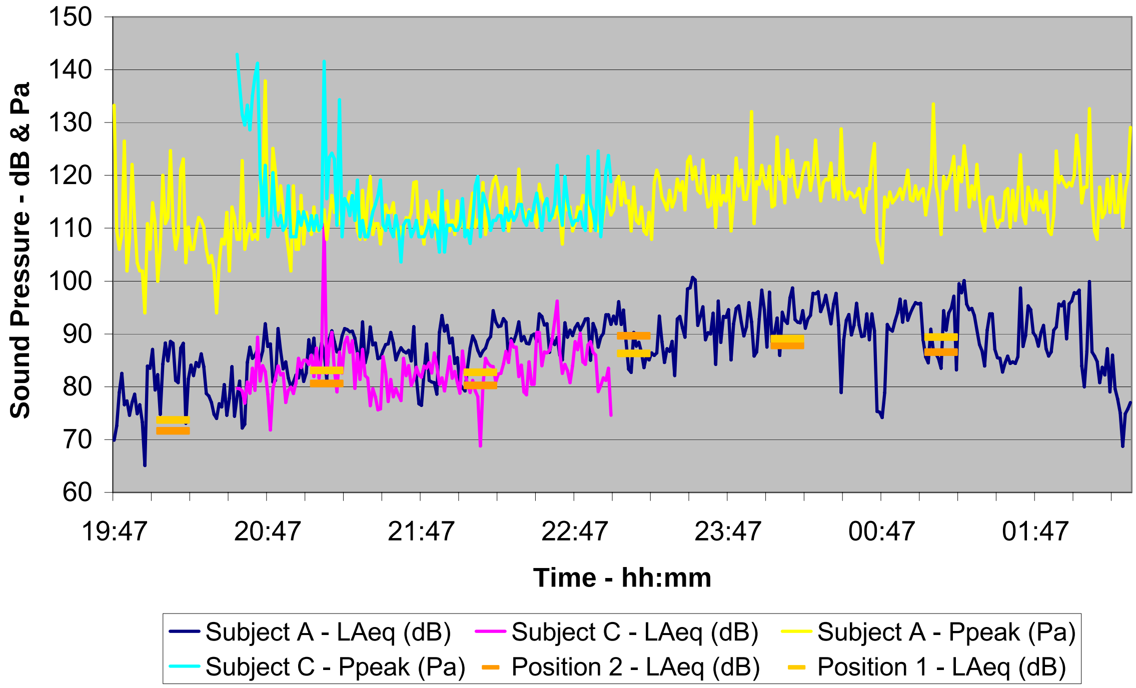


Figure 2.4 –Noise badge L_{Aeq}, P_{Cpeak} and SLM L_{Aeq} measurements taken during the Thursday shift

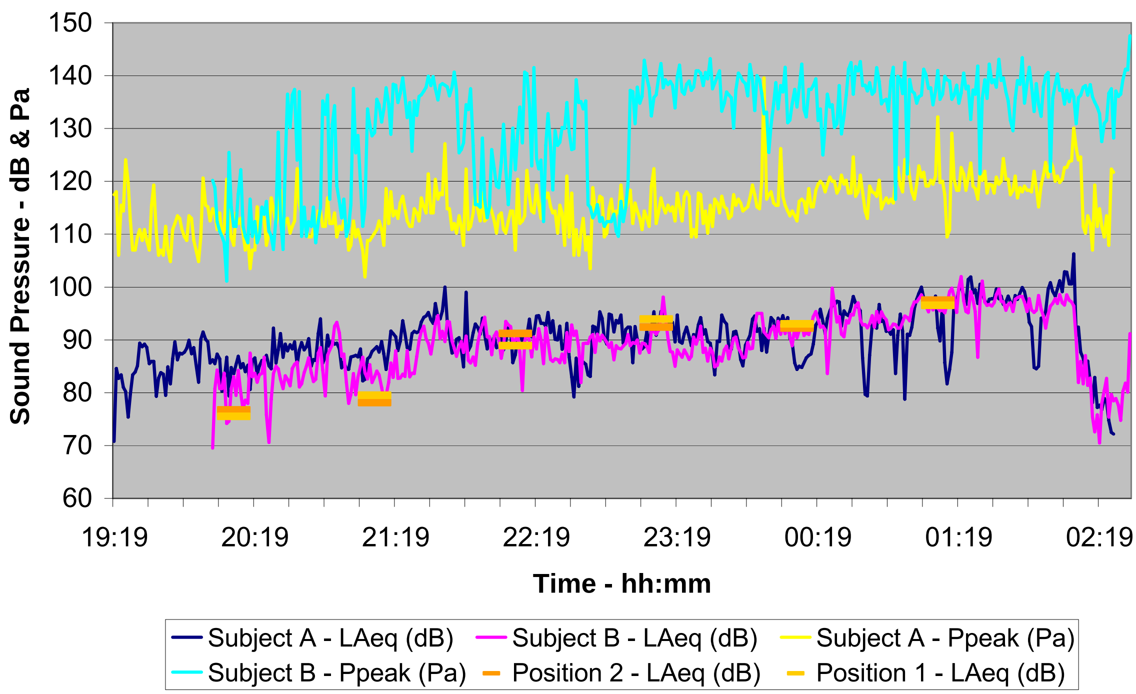


Figure 2.5 – Noise badge L_{Aeq}, P_{Cpeak} and SLM L_{Aeq} measurements taken during the Friday shift

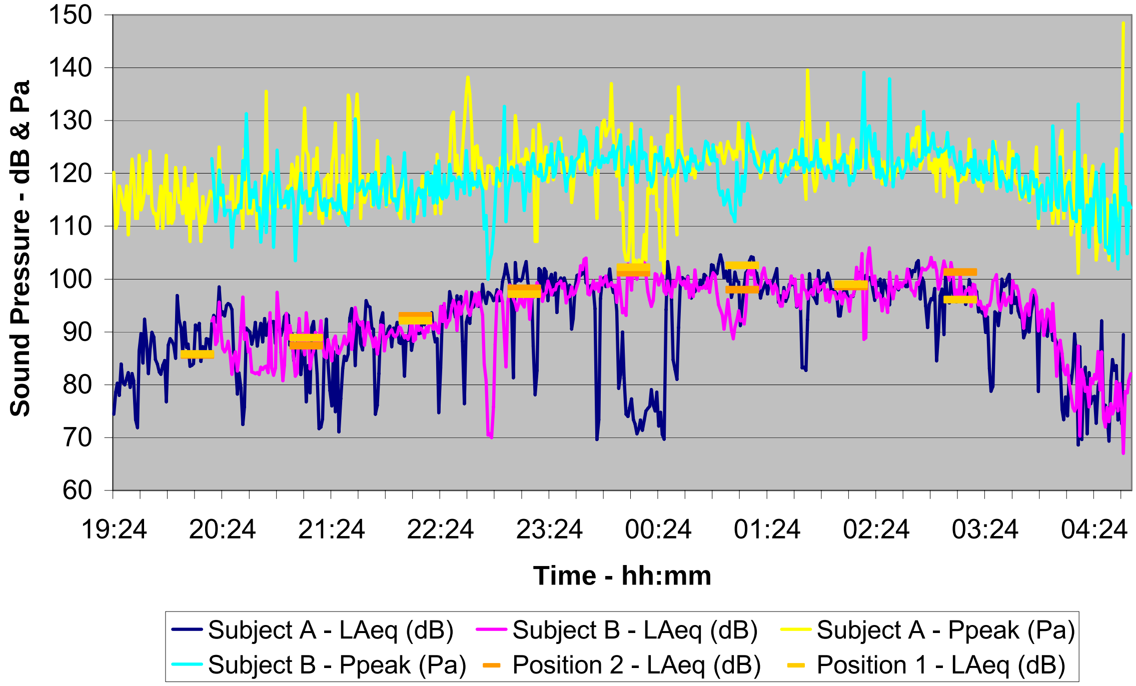


Figure 2.6 – Noise badge L_{Aeq}, P_{Cpeak} and SLM L_{Aeq} measurements taken during the Saturday shift

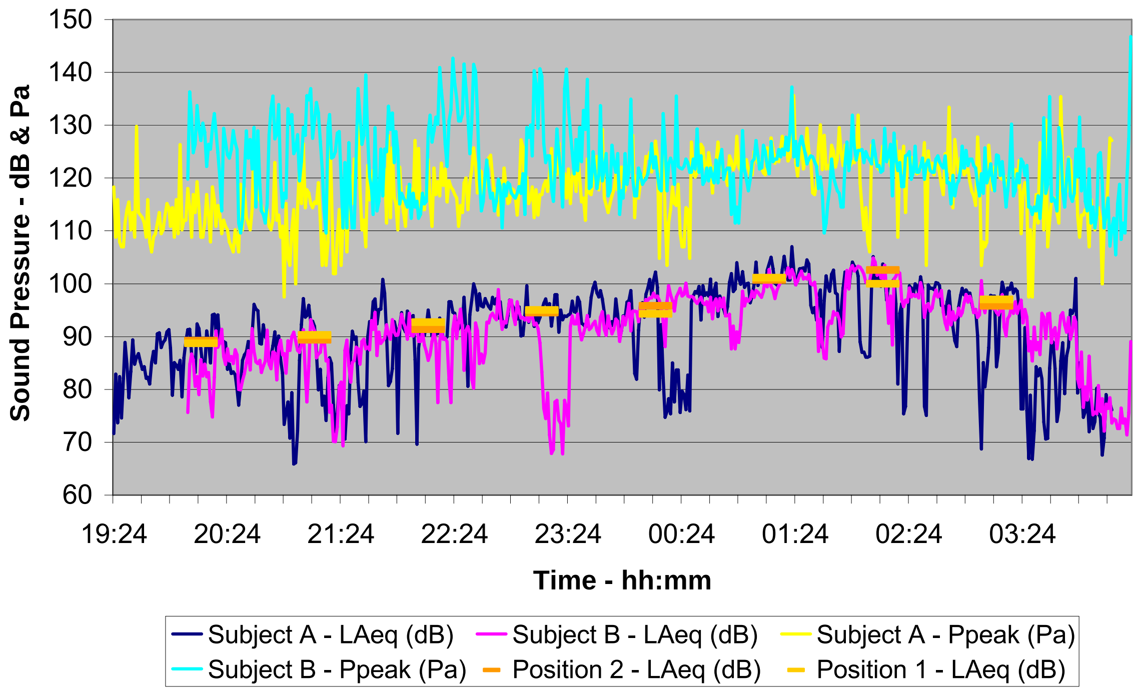


Figure 2.7 – Noise badge L_{Aeq}, P_{Cpeak} and SLM L_{Aeq} measurements taken during the Sunday shift

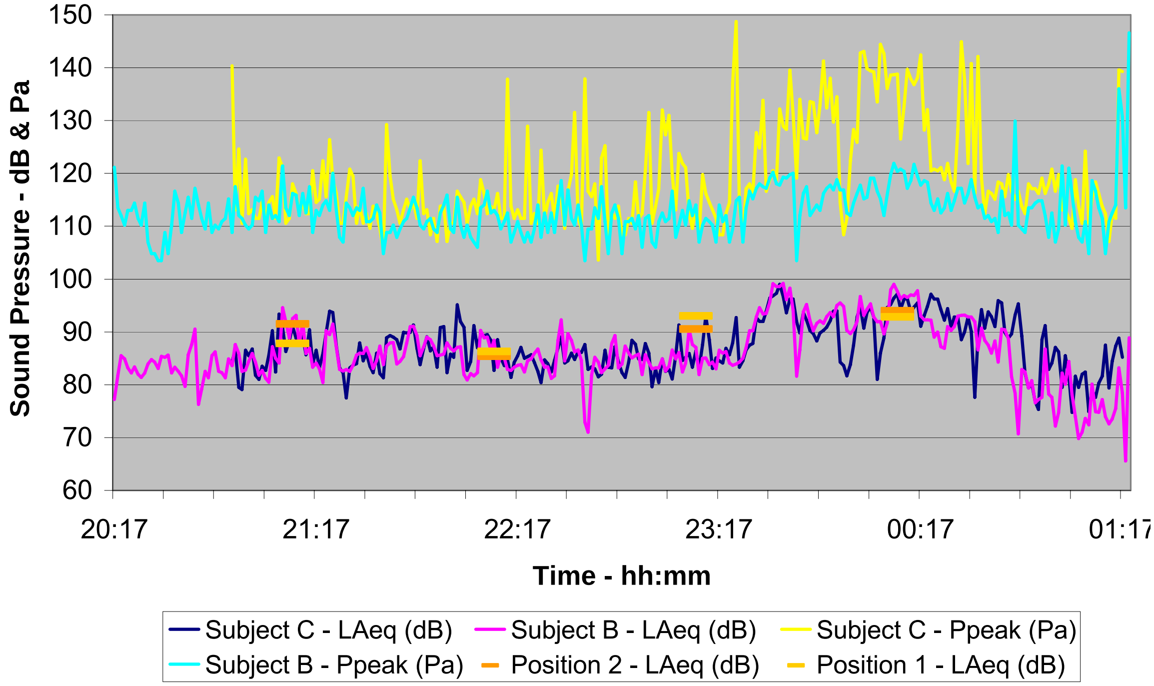


Figure 2.8 – Daily L_{Aeq} measurements for the entire shift period

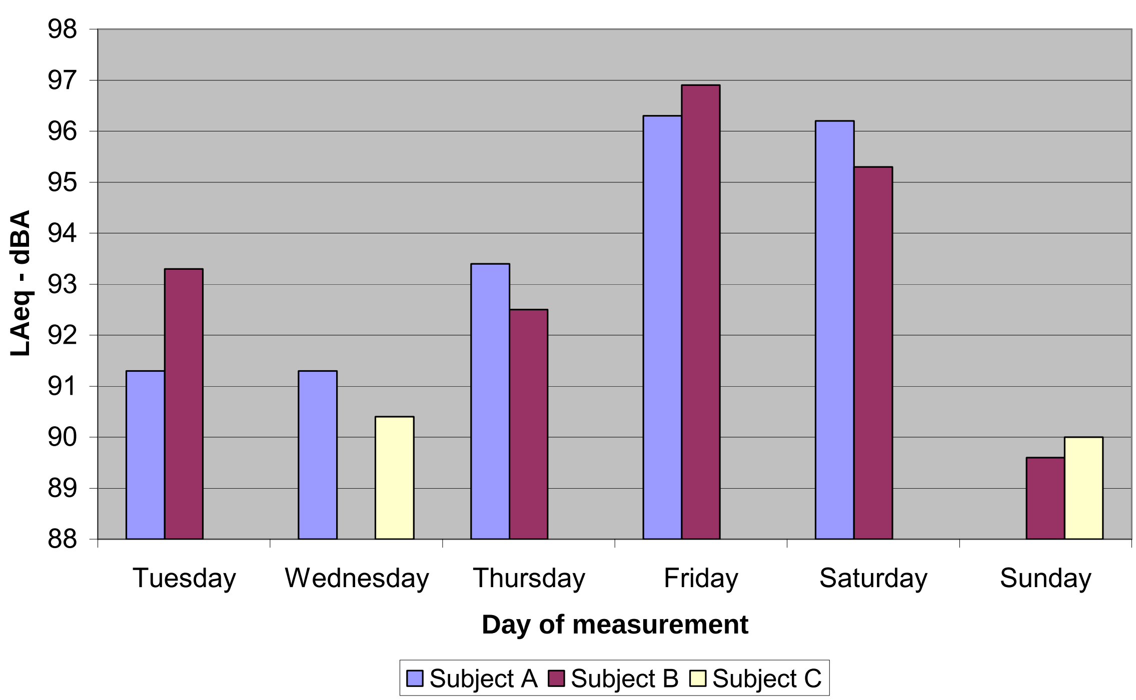


Figure 2.9 – Daily $L_{EX,8h}$ / $L_{EP,d}$ and weekly average $L_{EP,w}$ / $\overline{L}_{EX,8h}$ measurements

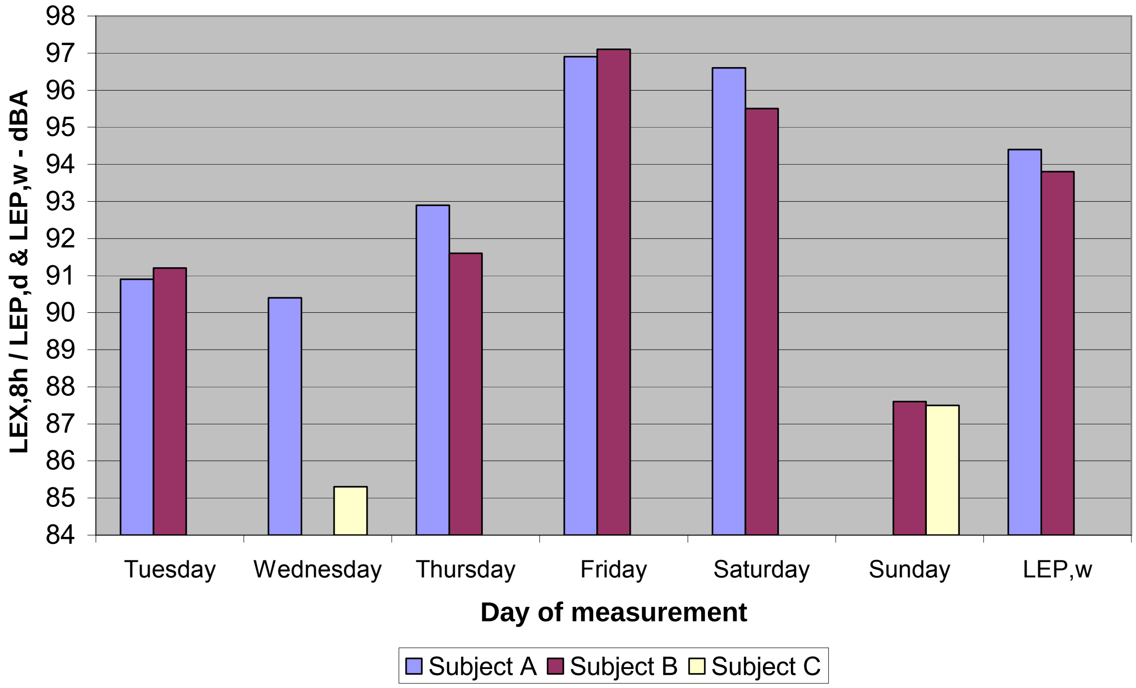
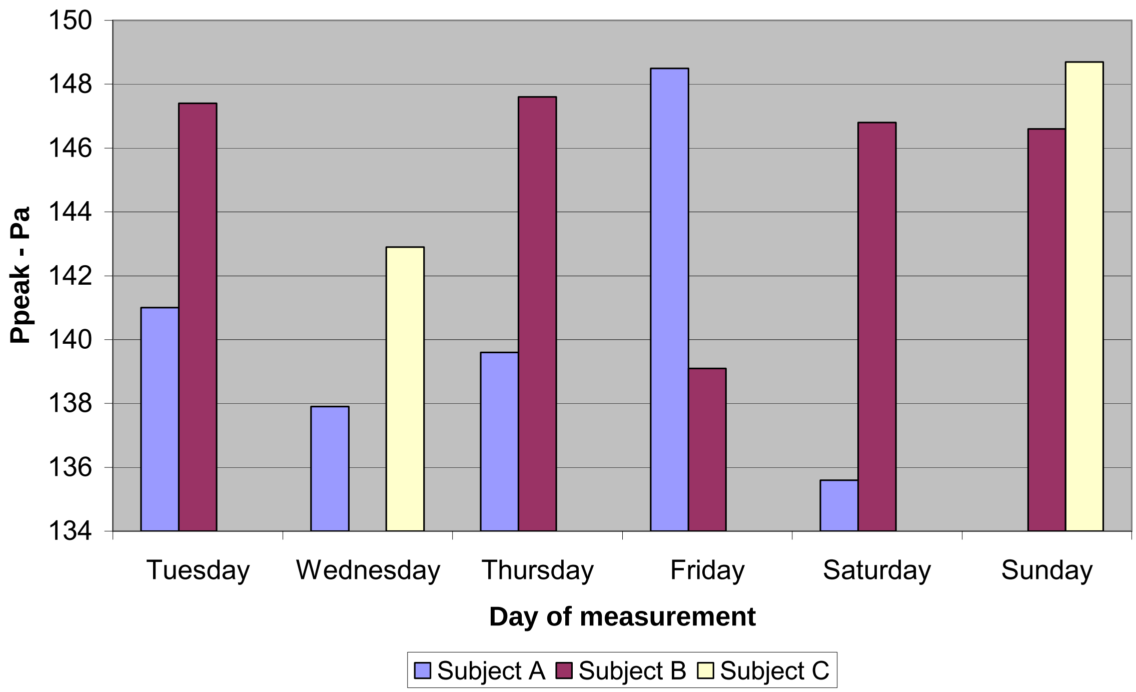


Figure 2.11 – Daily maximum P_{Cpeak} measurements for the entire shift period



2.5 – Analysis

The majority of the assessable data has derived from the noise badges and as such, a microphone has been attached at very close proximity to the subject's body. Because of this close proximity to the body the resultant data will have been effected by a disturbed field pressure. It is difficult to make appropriate adjustments for this factor because the significance of this disturbed field pressure is difficult to accurately quantify. This is because the disturbed pressure field is created by non-uniform reflections governed by the frequency dependent absorption and diffusion characteristics of each subject and the clothes they are wearing. However, there is a likelihood that reflections from the body should be compensated for by a reduction of somewhere between 0 and 3dB. Therefore, when considering the noise badge resultant data in terms of the Directives provisions, an uncertainty factor of up to -3dB is justifiable.

Although on each day the subjects sifts began and ended at different times, when overlapping, for the majority of the shift duration there is relative unison between the pair of noise badge L_{Aeq} values along the time line (*Figures 2.2 – 2.7*). The reason for this is because for the majority of their shift periods, the subjects work in close proximity to one another behind the bar.

At different locations around the club the average SPL varies and in section 3 these differences are evaluated and presented in a map displaying the relative SPLs throughout the working area of the club *(Figure 3.4, Page 59)*. Because of these SPL differences when one of the subjects leaves the bar area, e.g. to go to the toilet, for a break or to collect glasses, the subjects is exposed to different sound fields and this accounts for the more significant deviations between the comparative pairs of measurements. The most significant deviations between the comparative measurements were probably caused because a subject left the building or was required in the office that's located in the basement.

In general, the number of customers increases throughout the course of the night and thus in turn, as a bigger group, the customers create more noise. In addition to the quantity of customers, the longer they stay and the more they drink, there is a tendency for them to produce more noise. The DJ who at least partially operates the level of the PA system tends to compensate for this by turning up the volume. This acts as a kind of positive feedback loop where the louder the music, the louder the customers and vice versa. It is also true that independently of customer numbers and crowd noise, the majority of DJs if given the opportunity have a tendency to keep turning the volume up throughout the course of the night.

It should be noted that there is no specific system in place to control the output level of the PA system on any particular night. In the main bar there are two independent forms of PA volume control. The first is a level dial control behind the bar that directly controls a sound mixer device feeding the amplifiers in the amp room (see the PA system pages 9 - 10). The second are the various faders and dial controls on the DJ mixer in the DJ Booth. On some occasions the bar control is permanently left at a maximum and the responsibility of PA level is left solely with the DJ. On other occasions, the level is controlled from behind the bar by a member of the staff and as such, the sound levels are controlled by both DJ and bar staff/management.

By studying the sample L_{Aeq} measurements (*Figures 2.2 – 2.7*) this pattern of increasing level is evident on each of the six sets of results. On the Tuesday, Wednesday, Thursday (*Figures 2.2 – 2.4*) this pattern is gradual and relatively consistent across the duration of the shift peaking towards the end of the shift at around 100dBA. On the very busy Friday and Saturday nights however, (*Figures 2.5 & 2.6*) the levels increase much more quickly. On the Friday the level peaks at approximately 100dB from around 11pm and remains at that level until around 03:30am. This suggests that the maximum output of the PA system was reached. Although the results from the Saturday suggest a peak level of approximately 103dBA, this could have been achieved by turning all of the EQ setting on mixer up together (A common practice for less professionally inclined DJs). The sample L_{Aeq} results for the Sunday (*Figure 2.7*) show that only towards the end of the evening was the PA turned up and this reflects a low and late arriving number of customers on that particular night.

Because of the extended hours on the Friday and Saturday it is common for many of the customers to start leaving from around 2am. It is this reason that may explain why on these particular days, there is a more gradual reduction in the L_{Aeq} exposure levels towards the end of the shifts. Although there is a possibility that the DJ or a member of the staff may have reduced the PA levels to compensate, this is unlikely. A far more probable cause is that a significant proportion of the overall sound levels on these nights are made up from the customers. When considering that there can be in excess of four hundred people in the club on a weekend, this is perhaps not surprising. What is common to all of the sample L_{Aeq} results is a relatively steep reduction towards the very end of the shifts and this occurs when the DJ finishes for the night.

Because the exact time in which the measurements taken using the SLM were not recorded, it was not possible to compare them directly with the noise badge measurements. However, from the approximate positioning along the time axis, on all six days they nearly all appear to be well aligned with the comparative noise badge measurements. Because it was not possible to calibrate the noise badges, the alignment between sets of results suggests that the lack of calibration did not significantly effect the accuracy of the measurements. It also suggests that the noise badge uncertainty factor may be relatively insignificant.

Much of the sample L_{Aeq} analysis can also be applied to the sample P_{Cpeak} results. For all six sets of results there is, although on a different scale, a general alignment of magnitude between these and the L_{Aeq} measurements across the shift periods. What is not consistent for large sections of the shift periods on several of the days is the unison between each pair of P_{Cpeak} results. This is particularly significant on the Sunday (*Figure 2.4).* On this day the pair of L_{Aeq} results are for the majority of the shift in relative unison. However, The pair of P_{Cpeak} values on this day display a significant deviation for the majority of the shift. There is a possibility that this could have been caused by a device or software error and although not impossible, this is unlikely. A more plausible explanation is that the microphone was attached in such a way that the subjects movement caused the microphone to rub, or tap a hard part of the subjects clothing such as a button or necklace. This kind of contact could of gone unnoticed by the subject and observer but would give the impression that the subject was exposed to far greater P_{Cpeak} levels than in actuality.

This kind of short duration transient signal would, even if repeated several times within the sample period, make little difference to the L_{Aeq} result. The reason for this is because the total duration of even multiple transient signals would be insignificant in relation to the total sample period.

For large periods of each shift the deviation between the pairs of P_{Cpeak} data is comparable to the deviation between the L_{Aeq} results. This indicates that for those periods the values are likely to be a true reflection of the P_{Cpeak} exposure and should be evaluated when considering the provisions of the Directives. However, where there is a significant and prolonged period of deviation between the sets of P_{Cpeak} results and not the L_{Aeq} results, the data should not be evaluated in terms of the Directive provisions.

For this reason it would be unrealistic to asses whether the Directives P_{Cpeak} action values have been exceeded from the daily maximum P_{Cpeak} measurements for the entire shift period *(Figure 2.10)*. To make this assessment it is necessary to analyse the individual P_{Cpeak} measurements across each shift period filtering out and ignoring sections that display the error in measurement discussed previously. It is also realistic to ignore any spurious values at the very beginning and end of the shifts. The reason for this is because it is likely that last minute adjustment at the beginning of a shift and removing the devices at the end would produce spurious and unrealistic values.

When considering the new Directive it is clear that on each of the days the lower exposure action value (112Pa) is exceeded. This is also true after accounting for the uncertainty factor described previously. However, after filtering spurious and/or deviating P_{Cpeak} values it is likely that at no point throughout the week was the upper exposure action value (140Pa) exceeded. Independently of whether this spurious and/or deviating P_{Cpeak} filtering is undertaken, it is clear that on no occasion do the P_{Cpeak} values ever exceed the existing Directives upper exposure action values or the future Directives exposure limit value (200Pa).

Because of significant variation between the daily $L_{EX,8h}$ / $L_{EP,d}$ exposure values (*Figure 2.9*), a calculation of the average weekly noise exposure ($\overline{L}_{EX,8}$ / $L_{EP,w}$) was required by both Directives. When considering these values (94.4dBA and 93.3dBA) in terms of the Directives provisions, it is clear that all of the exposure values in both Directives have been exceeded. This is also true when accounting for the uncertainty factor of -3dB discussed previously.

Although with less bearing in terms of the Directive because of the weekly average, it is of interest to analyse the daily $L_{EX,8h}$ / $L_{EP,d}$ results and for simplicity of definition, the uncertainty factor will not be considered.

On every day other than Sunday and Subject C on Wednesday, the upper exposure values of both Directives (85 & 90dBA) has been exceeded. All of the individual results exceed the upper exposure value of the future directive (85dBA) and only the result for subject C on Wednesday is less than the exposure limit value (87dBA).

Although the $L_{EP,d}$ results for subject C on Wednesday and subjects A and B on Sunday do not exceed the current Directives upper exposure value (90dBA), they do exceed the lower value (85dBA). However, when assessing the respective shift durations *(Table 2.5)*, 02:27:25, 04:26:11, 05:03:15 (hh:mm:ss) and respective L_{Aeq} values for these shifts *(Figure 2.8)*, 90.4dBA 89.6dBA 90dBA, it is apparent that it is the shift duration, rather than the shift L_{Aeq} that accounts for the reduced $L_{EP,d}$ values. When comparing these shift durations with the average durations (*See equation 2.2 for average calculations*), Subjects A = 07:51:31 and Subject B = 06:38:49 (hh:mm:ss), it is clear that these shifts were unusually short.

Calculation used to derive the average shift period for each subject

Equation 2.2

$$\text{Subject A} = \frac{07{:}25{:}28 + 06{:}38{:}36 + 07{:}07{:}37 + 09{:}17{:}18 + 08{:}48{:}36}{5} = 07:51:31\,(\text{hh}:\text{mm}:\text{ss})$$

$$\text{Subject B} = \frac{04{:}51{:}37 + 06{:}32{:}22 + 08{:}27{:}07 + 08{:}19{:}44 + 05{:}03{:}15}{5} = 06:38:49\,(\text{hh}:\text{mm}:\text{ss})$$

2.6 - Implications of the Directives and Further analysis

Because the future Directive grants an additional two year transition period for music and entertainment sectors, its Regulations will not be applicable to the Dogstar until 6th of April 2008. Although a certain degree of forethought and planning for this period would be commendable in terms of staff health and safety, the likelihood of this occurring is minimal. For this reason only the implications of the current Directive will be looked at in any detail.

It has been made clear that the average weekly noise exposure of the bar staff exceeds the upper exposure action $L_{EP,d}$ value of the Directive. Because of this, it is the legal responsibility of the employer to comply with the Directives regulations described in the literature review (*Pages 13 - 17*).

It should be noted that currently there is absolutely no compliance with any of the regulations of the Directive. This may be because the club has a fast turnaround of management and staff and any provisions of compliance from the past have been lost. However, as there is no evidence of any kind for these provisions, it is unlikely that they have existed for a long period, if indeed ever at all.

The most important first step that must be taken by the employer is to acquire and ensure that the bar staff wear ear protection for the duration of each of their shifts.

However, in practicality, the instigation of this procedure would be a cause of concern for the business because of the requirement for staff to communicate with customers verbally. Communication is a fundamental requirement of the job that is necessary throughout the shift period. It is already problematic when the club is busy and usually requires both customers and staff members to raise their voices considerably, almost to the point of shouting. The use of standard ear protection systems could make verbal communication imposable and at the very least, more problematic.

To alleviate this problem specialist and custom made hearing protection systems could be implemented. Some of these systems are designed to collectively attenuate the whole frequency spectrum allowing the user to hear a more evenly balanced and natural sound. By using such devices, noise exposure would be reduced but the audibility of customers would be maintained.

The Directive states that independently of hearing protection systems, the employer must devise and execute a series of measures that are designed, so far as is reasonably practicable, to reduce the exposure of noise to an employee. This program of measures must incorporate where appropriate, both technical and organisational forms of accomplishing this.

With regard to organisational measures, there is only one specific area of work for a bar person and that is, behind the bar. Because of this it is not possible to alternate the duties of different employees to different and quieter locations. This is not only impossible because there are no other duties at different locations around the club, but because with the exception of the back room there are few significantly quieter areas within the club.

With regard to technical measures this implies reducing the noise level at source or along its path. The only sources of noise in the club that are significant in terms of noise exposure, are the PA system and the noise made by the customers. As the noise levels produced by the customers is partially governed by the level of the PA system, reducing its output level is the only practical method to reduce by technical means the exposure of noise to an employee. However, the noise output from the PA is not an unwanted by-product of another mechanism, it is a fundamental design feature of the club.

The positioning of the speaker array around the club could be analysed in terms of reducing the sound levels behind the bar area. However, because the majority of the loud speakers are already located at a significant distance away from the bar, it is unlikely that a rearrangement of their relative positions could make much of a difference.

It is impractical to expect a nightclub that has a reputation and customer expectation for being comparatively loud, to turn down the PA system by a significant amount. What is more practical and less compromising in terms of reputation and customer expectation, is the implementation of a more controlled system to govern the output level.

As discussed previously, there is no specific system currently in place to govern the sound system and as the results indicate, this creates irregular and unpredictable levels of sound exposure throughout the week. It would not be difficult to implement a system where the level of the PA was gradually and systematically increased and/or limited from behind the bar in a manner that could be repeated on nights of similar duration. In this way, a balance could be found that minimised and regulated the noise exposure of the employee, without significantly compromising the clubs reputation/customer expectation.

In areas that exceed the upper exposure values the Directive requires, where reasonably practicable, that those areas are delimited and access to them restricted. It also requires the use of signs warning of the dangers. In practicality this requirement is difficult to satisfy because at certain times the entire club exceeds these levels. The implication of the Directive is that at certain periods access to the whole club must be restricted and that signs must be positioned throughout the club. Clearly it is not reasonably practicable to restrict access to the entire club and because the levels are only exceeded at certain times, permanent warning signs would be inappropriate.

To comply with the current Directive the employers must insure that ear protectors with an attenuation of at least 8dBA are worn by bar staff throughout the week *(This 8dBA attenuation value was derived by subtracting the maximum $L_{EP,d}$ value (97.1dBA) from the upper exposure value (90dBA) and rounding up to the nearest whole number)*. This would ensure that the upper exposure value was not exceeds by the $L_{EP,w}$ value, and at any point during the week by the $L_{EP,d}$ value. With an attenuation rating of only 8dBA the employers must also ensure that a shift period never exceeded the maximum period recorded in the week of testing. However, it would be advisable in providing some flexibility to a shift duration, to increase the attenuation rating of the hearing protection provided.

If as discussed previously a method was implemented to more carefully control the output of the PA system, a $L_{EP,d}$ reduction of 3dBA or more may be obtainable. If this was accomplished and measures were taken to ensure that on Tuesday to Thursday and on Sunday the shift period did not exceed the weekly average, on these days the upper exposure limit of 90dBA would not be exceeded. *(This 3dBA value was confirmed as sufficient by subtracting the maximum $L_{EP,d}$ value of the pre-mentioned days (92.9dBA) from the upper exposure value (90dBA) and rounding up to the nearest whole number)* This would reduce the employers responsibilities and give employees the opportunity to choose whether or not they wanted to use the ear protection on those days.

When considering the implications of the future Directive it would be necessary for employees to ensure staff used hearing protection throughout the week. The reason for this is because control of PA system would have to reduce the $L_{EX,8h}$ value by a realistically unobtainable 8dBA to fall below the 85dBA upper exposure value. *(This 8dBA was derived by subtracting the maximum $L_{EX,8h}$ value (92.9dBA) of the pre-mentioned days from the upper exposure value (85dBA) and rounding up to the nearest whole number)*. It is worth noting that the exposure limit value (87dBA) has not been considered because its use is only applicable after accounting for attenuation provided by hearing protection.

When considering the minimum attenuation required to reduce the maximum $L_{EX,8h}$ to a level below the upper exposure value of 85dBA, an attenuation of 13dBA would be required. *(This 13dBA value was derived by subtracting the maximum $L_{EX,8h}$, value (97.1dBA) from the upper exposure value (85dBA) and rounding up to the nearest whole number)*. However, because the effects of attenuation are incorporated and there is significant variation between the individual $L_{EX,8h}$ values across the week, the minimum attenuation could be reduced to 11dBA. *(This 11dBA value was derived by subtracting the maximum $L_{EX,8h}$, value (97.1dBA) from the exposure limit value (87dBA) and rounding up to the nearest whole number)*. This would ensure that both the maximum $L_{EX,8h}$ never exceeded the exposure limit value and because the protection would be used throughout the week, the $\overline{L}_{EX,8h}$ would be less than the upper exposure value. However, as discussed previously, by implementing a minimum protection attenuation value employers must be careful to monitor shift durations.

2.7 - Conclusion

There is significant deviation between daily $L_{EP,d}$ / $L_{EX,8h}$ values for both subjects and this is because of three central reasons. Although the noise levels produced by customers can be controlled to a certain extent by the level of the PA system, essentially, these levels are unpredictable. The subject's shift period and duration varies from day to day. There is no specific system in place to control the output level of the PA system and this creates irregular and unpredictable levels of sound exposure.

Noise badges are an effective tool for measuring the $L_{EP,d}$ / $L_{EX,8h}$ noise exposure values. However, using them to measure the maximum P_{Cpeak} exposure of a employee is questionable. The reason for this is because a single inadvertent tap of the microphone by a subject could falsely indicate that a P_{Cpeak} Directive exposure action value had been exceeded.

Currently the weekly sound exposure of the two subjects tested exceeds the upper exposure action values of the current and future Directives. However, it should be noted that only the maximum $L_{EP,d}$ / $L_{EX,8h}$ noise exposure values have been exceeded and not the maximum P_{Cpeak} values.

The PA system is the most significant cause of noise exposure to employees. However, it is also an essential design feature of the club that has a reputation and is expectation to be comparatively loud. Because of this, there is little that can be done to reduce the employees exposure to noise other than implementing hearing protection.

To comply with the current and future Directives the employers must insure that ear protectors with an attenuation of at least 8dBA and 11dBA respectively are worn by bar staff throughout the week. These minimum attenuation values are only viable if the shift durations from the week of measurement are not exceeded. However, for practical purposes such as shift duration flexibility, it would be advantageous for hearing protection with attenuation that exceeds these minimum requirements to be utilised.

If measures could be taken to reduce the existing $L_{EP,d}$ values by 3dBA on Tuesday to Thursday and on Sunday, the current upper exposure limit of 90dBA would not be exceeded. This would reduce employers responsibilities and give employees the opportunity to choose whether or not they wanted to use the ear protection on these specific days.

When the club is busy, communication between customer and employee is relatively problematic and requires both customers and staff members to raise their voices considerably. As standard hearing protection would serve to worsen this problem, the use of specialist systems that minimised sound pressure without compromising the audibility of customers would be advantageous.

Many of the implications discussed in this section are a matter of legal requirement. However, currently there is absolutely no compliance with any of the Directive's regulations. Because the Directive has been in place for over sixteen years and it is likely that no provisions have ever been made for it, it is also likely that unless enforced by a government body, they never will be.

Section 3 – SOUND DISTRIBUTION & EQUALISATION STRATEGY

3.1 – Introduction and Ideology

In the majority of night clubs it is recognised that the effectiveness of the PA system is of great importance in terms of customer satisfaction. Independently of the type of music played, there is an expectation for it to be well balanced, clear and properly distributed. The definition, or audio quality, is partly dependent on the quality and settings made on the actual PA system, but also on the building acoustics and loudspeaker distribution.

As discussed in section one, although there is a general expectation for the PA system to be very loud, this is mainly a requirement focused on the dance floor. Ideally, the sound levels in the seating areas should be less than on the dance floor to allow for conversation. In addition to the seating areas, because of the health and safety issues discussed in section one, ideally, areas in which staff work should also be less noisy.

It is difficult to define the term “well balanced” in the context of sound quality and frequency weighting because every DJ, sound engineer, musician, club promoter and customer has a different opinion on this matter. However, before a PA system is subjectively balanced using equalisation, there should be a equal level of fidelity without distortion or coloration across the frequency spectrum.

When a DJ is performing a set, he or she needs to be able to hear a mix that is separate from that sent to the PA system. This mix is adjusted and controlled by the DJ and is fed into a loud speaker known as a DJ monitor positioned at a very close proximity. The mix sent to the DJ monitor will be set via an independent amplification system so that it is loud enough for the DJ to hear above the background noise of the PA system. It is used by the DJ for several purposes including helping to perfect and check a mix, but also so that the DJ can accurately monitor what they are playing and the effects of any EQ settings they might employ.

Because the EQ settings will feed on to the PA system, it is important that the DJ monitor speaker is also correctly balanced and produces an output frequency response that is directly comparable to that of the PA system. In this manor, the DJ will be able to hear exactly what the customers here and be sure that any subtle equalisation adjustments observed on the DJ monitor will be faithfully reproduced over the PA system.

One of the central aims of this section was to develop an equalisation strategy that could be used to equalise and flatten out any distortions created by the nightclub's acoustics, PA system and DJ monitor. An additional aim was to assess the current patterns of sound distribution throughout the club in terms of general level and the frequency characteristics. To develop these strategies and make the assessments, a pink noise source was fed into the PA system / DJ monitor and a series of broadband L_{Aeq} and third octave band L_{eq} measurements were taken throughout the club.

3.2 – Instrumentation

Sound level analyser. CEL 593. *Serial number 073104*

Calibrator. Cirrus CRL511D. *Serial number 011932*

Lap top computer – Dell Inspiron 8600 *Serial number – X08 73061*

Software:

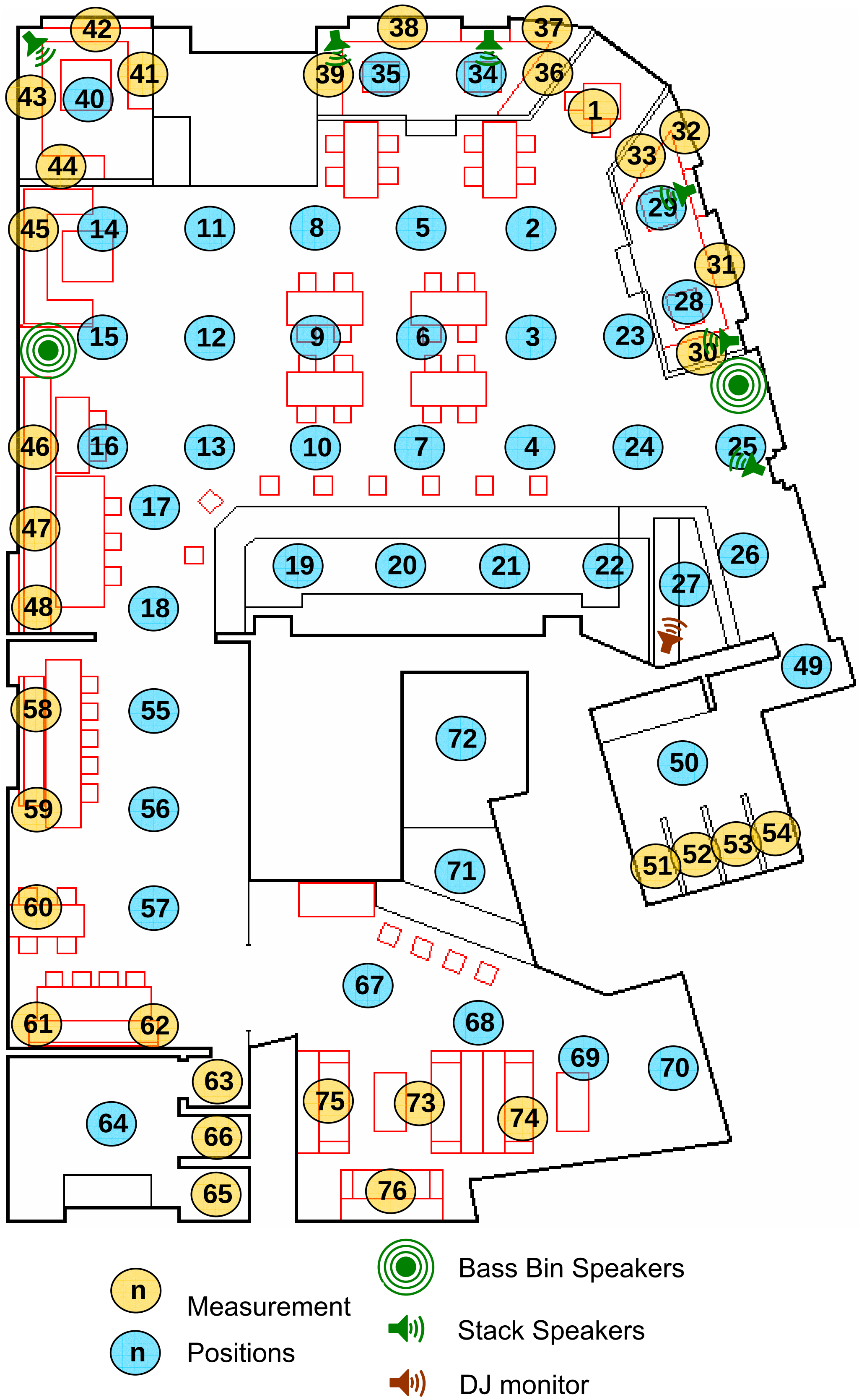
- Cool Edit Pro, version 2.1a
- CEL Sound Track – dB1 32 bit Version 4.01

3.3 – Method and Procedure

This section of the document will be broken down into a sequential step by step account of how and why the various measurements were taken. All of the measurements were taken on a weekday when the club was closed to the public between the hours of 4am to 1pm. Throughout this period there was only ever one person in the club.

In total, seventy six measurement positions were used to map out the nightclub, and over two hundred individual measurements were taken. Figure 3.1 provides a plan diagram of the club displaying the measurement positions and the location of the various loudspeakers employed throughout the club.

Figure 3.1 – Plan diagram of the club displaying the measurement and loudspeaker positions

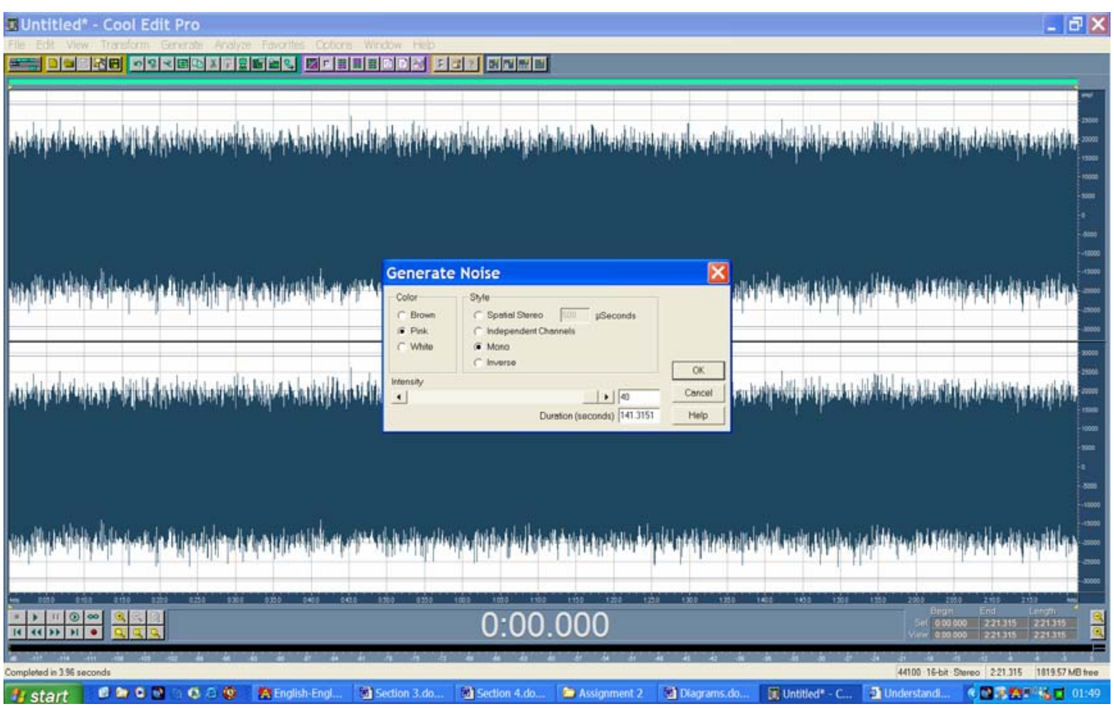


The measurements recorded at the yellow and blue positions were taken at heights of 1.2m and 1.7m respectively to simulate the standing and sitting ear height. Exact coordinates for each position have been included in the appendix *(Page 121)*. The stack speakers were all attached to the wall at a central height of three meters angled to point down and towards the centre of the main room. The bass bin speakers were all positioned on the floor with a central height of 50cm and the DJ monitor was positioned at a height of 1.5m from the floor of the DJ booth. The quantity and distribution of the measurement positions were selected so that an analysis of the entire club area including all major standing and seating positions could be made.

> **Step 1.** All of the various measurement positions were carefully measured out and chalked on to the floor or seating areas.

> **Step 2.** A thirty minute mono sixteen-bit sample of pink noise at a sample rate of 44.1KHz and normalised at 0dB was generated in the software application Cool Edit Pro.

Figure 3.2 – Screen shot of Cool Edit Pro



0dB represents the maximum level of signal generation without clipping utilising the full dynamic range of the samples digital resolution. This means that because of the line level standardisation employed by most audio systems, the signal level fed to the mixer was the maximum attainable before the occurrence of digital clipping.

Pink noise was selected as the noise source because of its properties of having an equal quantity of energy per octave band. This property is more comparative to a music signal than white noise but more importantly, it is ideal for measuring the frequency response of an audio system. This is due to there being an equal distribution of sound energy in each octave band. Because of this property, an octave or third octave band L_{eq} measurement taken over a sufficient period should measure an equal distribution of sound pressure in each band. Therefore, any deviation from an equal distribution can be attributed to the distortions created by the building acoustics and PA system.

> **Step 3.** The output from the computer's sound card was connected directly to an auxiliary input of the DJ mixer and the EQ settings on the mixer were deactivated.

By connecting directly into the mixer, the signal was subjected to all the same possible causes of distortion as a music signal fed from the record or CD players. The EQ settings were deactivated so that the any signal distortions would be independent of these settings.

> **Step 4.** The remote volume control (see section one – the PA system *pages 9 - 10*) behind the bar was set to maximum.

This was adjusted so that control of the PA systems full dynamic range was available on the DJ mixer. This was partly for convenience of adjustment but also because this is the most commonly utilised configuration in the club.

In the process of developing an equalisation strategy, it was necessary to establish whether the PA system output frequency response altered at different output levels. By studying the noise exposure L_{Aeq} values from section 2 (*See Figures 2.2 – 2.7 Pages 28 to 31*), it was determined that the sound levels in normal opening hours vary between around 80 and 105dBA. To analyse the frequency response within this dynamic range it was decided that four sets of measurements at level of 80, 90, 100 and 110dBA would be sufficient. However, limited by the maximum output level of the PA system it was necessary to reduce the 110dBA value down to 107dBA.

It should be noted that as a record player is an analogue based system, it is not limited to the finite dynamic range of a digital system. Because of this, its output level can be greater than a digital system and as such this maximum output level of 107dBA could be increased when playing music through a record player. In addition, the EQ controls on the DJ mixer could also be used to increase this level.

Because of the requirement for measurements at these different output levels a single position was required for purposes of level calibration. From preliminary measurements taken previously, it was established that the loudest point in the club was somewhere near to position 2 and for this reason it was used as the calibration position.

Step 5. The SLM was placed in its stand, calibrated and moved to position 2.

Step 6. The SLM was set up to measure the real-time broadband SPL in dBA.

Step 7. The output from the DJ mixer used to feed the DJ monitor was disconnected.

Although the DJ monitor makes up a constituent part of the total sound field in the club its relative significance is minimal. In addition, the volume and use of the DJ monitor is intermittent and often used to play a separate mix than that sent to the PA. Because of this intermittent and unpredictable relationship between the outputs of the

PA and DJ monitor, it was determined that the DJ monitors contribution to the sound field would be disregarded.

Step 8. The pink noise was activated and the DJ mixer's master output fader was adjusted so that a level of 100dBA was being measured on the SLM.

Step 9. With the pink noise running on a loop cycle the SLM was set up to measure broadband L_{Aeq}, moved to the first measurement position and a measurement was taken and recorded within the SLM.

When taking an L_{Aeq} measurement its alternating value is displayed in real time. Because of this function it is not necessary to define a fixed measurement duration and was manually concluded when the level appeared to have stabilised.

Step 10. The SLM was moved to each of the 76 positions and a broadband L_{Aeq} measurement was taken at each and recorded in the SLM.

These measurements were taken so that the broadband sound distribution throughout the club could be assessed.

Step 11. The SLM was set up to measure 1/3 octave band L_{eq}, moved back to position 1 and a measurement was taken and recorded in the SLM.

All 1/3 octave band L_{eq} measurements were taken over a frequency range of 20Hz to 20KHz. This range was selected because it is generally accepted as the scope of audible perception[(3)]. As with the broadband L_{Aeq} measurements, the final values were recorded when the levels had stabilised.

Step 12. The SLM was moved to each of the remaining 76 positions and a measurement was taken at each and recorded in the SLM.

Figure 3.3 – Picture of one of the measurements being taken.

These measurements were taken so that the PA system's effective frequency distribution throughout the club could be analysed. They were also taken to help in the attainment of equalisation strategy as discussed previously.

The method for developing an equalisation strategy is based on the utilisation of a 1/3 octave band graphic equalisation system to compensate for the distortions created by the PA system and building acoustics. Because of the properties of pink noise discussed previously, the equalisation values could be derived by inverting an average of the measured deviations from an equal distribution of sound pressure in each band.

When the club is busy, the four sets of tables and chairs in the centre of the main room (see figure 3.1) are cleared away and this area becomes the dance floor. As this area is most important in terms of sound quality and because it is in the middle of the speaker array, it is this area that the equalisation strategy was focused on. As the whole of this area is covered by measurement positions 2 to 13, 23 and 24, it is the deviations from these positions that were used in the averaging process of the equalisation strategy. For convenience of terminology, this group of measurements positions will be collectively referred to as the “focus group” for the remainder of the document.

Step 13. The SLM was set up to measure the real-time broadband SPL in dBA, moved to the level calibration position (Position 2) and the DJ mixers master output fader was adjusted so that a level of 80dBA was measured on the SLM.

Step 14. The SLM was set up to measure 1/3 octave band L_{eq} and measurements were taken at all positions in the focus group and recorded in the SLM.

Step 15. Steps 13 and 14 were repeated for two remaining measurement level of 90dBA and 107dBA.

As discussed previously, it was also necessary to develop an equalisation strategy for the DJ monitor. The same method used for the PA system was also used for the DJ monitor with the exception of the averaging process. The reason no averaging process was required is because only the DJ needs to hear a balanced signal from the DJ monitor and he or she will always be standing at position 27.

Step 16. The output from the DJ mixer sent to the DJ monitor was reconnected, the output to the main PA was disconnected and the remote volume control behind the bar was set to a minimum.

This was carried out to ensure that no signal could be sent to the main PA system and interfere with the measurements of the DJ monitor.

Step 17. The SLM was set up to measure the real-time broadband SPL in dBA, moved to position 27 and the DJ mixers monitor output fader was adjusted so that a level of 80dBA was measured on the SLM. The SLM was then set up to measure 1/3 octave band L_{eq} and a measurement was taken and recorded in the SLM.

Step 18. Step 17 was repeated for each of the three remaining measurement levels.

Because of a powerful DJ monitor amplifier it was possible to set up a 110dBA maximum output level instead of the 107dBA level used for the PA system.

Step 19. The pink noise source was deactivated and the DJ mixer was turned off.

Step 20. The SLM was moved to positions 12 and 24 and an octave band L_{eq} and a broadband L_{Aeq} measurement of the background noise level was taken at each.

The background noise measurements were taken to help quantify the relative output frequency bandwidth of the PA system in comparison to the noise floor, and this is why positions close to the bass bins were utilised. The use of an octave band rather than 1/3 octave band measurements was unintentional and a problem because of the incompatibility with the other 1/3 octave band results. However, this was overcome by logarithmically dividing the octave band values in to three, and substituting this average across the corresponding 1/3 octave bands. The formula used for this purpose is given below.

Equation 3.1

$$1/3\ \text{Octave Band}\ L_{eq} = 10\log_{10}\left(\frac{1}{3}10^{0.1(\text{Octave band}\ L_{eq})}\right)$$

Step 21. The SLM was connected to the computer and all the recorded measurements were downloaded and exported into a Microsoft Excel compatible file format using the CEL Sound Track software application.

Because of the large array of measurements, not all needed to be displayed independently in the main body of the document but have been included in the Appendix (Pages 122 to 137).

3.4 – Results

For display purposes the broadband L_{Aeq} measurements have been superimposed on to a diagram of the club at the specific locations at which they were measured. However, so that it is easier to identify and assess the relative sound distribution across the club, the maximum broadband L_{Aeq} value has been subtracted from each of the remaining values. In this manner, each position can be directly compared to a relative maximum without having to compare it with any other positions. In addition, a series of nine noise level attenuation categories have been devised and the values at each position have been colour coded accordingly. Category increment values of 1dB were utilised from 0 to -5dBA to highlight the sound distribution in the main room. The remaining categories were divided by increments of 5dBA.

To accurately calculate the average frequency response from the focus group of measurement positions, it was first necessary to normalise each set of measurements to their independent logarithmic average. The reason for this is because as the broadband SPLs vary from position to position, the 1/3 octave band measurements are offset from one another and so are not directly comparable. To accomplish this normalisation it was first necessary to calculate the logarithmic average of all thirty one 1/3 octave band values for each position. This average value was then subtracted from each of the individual 1/3 octave band values used to derive this average. The formula used for this process and applied to each 1/3 octave band is given on the following page.

Equation 3.2

$$\text{Normalised}\,L_{eq}\ (\text{dB}) = i - 10\log_{10}\left(\frac{1}{32}\sum_{i=20\text{Hz}}^{i=20\text{KHz}} 10^{0.1(L_{eq})}\right)$$

were, *i* = specific 1/3 octave band

This formula was applied to all the 1/3 octave band values measured at every source position at all the different output levels for both the PA and DJ monitor. By doing this, the effective frequency response at each position and at each measurement level was now directly comparable. However, because now normalised to 0dB, each respective set of results included both positive and negative values at different 1/3 octave bands. For this reason, before it was possible to calculate a logarithmic average from a number of different measurement positions, it was first necessary to positively bias all of the individual 1/3 octave band values. To keep the maths simple and ensure sufficient bias, a value of a hundred was employed. With all of the values now normalised and positively biased it was then possible to calculate a logarithmic average before negatively biasing the final results back down to zero. The formula used for this process and applied at the four output levels at each 1/3 octave band is given below.

Equation 3.3

$$\overline{\text{Normalised}\,L_{eq}}\ (\text{dB}) = 10\log_{10}\left(\frac{1}{14}\sum_{p=1}^{p=14} 10^{0.1(100+\text{Normalised}\,L_{eq})}\right) - 100$$

were, *p* = measurement position number *(it should be noted that in this instance, the term measurement position number is used to define the fourteen focus group positions and not the actual measurement positions defined by Figure 3.1)*

So that the relative differences between the individual 1/3 octave band values in each of the focus group positions could be assessed, the standard deviation between values measured at the 100dBA output level was calculated. The formula used for this process and applied to each 1/3 octave band is on the following page.

Equation 3.4

$$\text{Standard Deviation} = \sqrt{\frac{1}{14^2}\left(14\sum_{p=1}^{p=14}\left(\text{Normalised L}_{eq}\right)^2 - \left(\sum_{p=1}^{p=14}\text{Normalised L}_{eq}\right)^2\right)}$$

where, p = measurement position number *(it should be noted that in this instance, the term measurement position number is used to define the fourteen focus group positions and not the actual measurement positions defined by Figure 3.1)*

Because both the average PA system and DJ monitor effective frequency response curves at the four measurement levels were slightly different, a logarithmic average was calculated for direct use in the equalisation strategy. However, because each set of results had been normalised to 0dB, it was again necessary to implement the biasing process before averaging. The formula used for this process and applied to each 1/3 octave band is given below.

Equation 3.5

$$\overline{\text{Normalised L}_{eq}}\ (\text{dB}) = 10\log_{10}\left(\frac{1}{4}\sum_{n=1}^{n=4}10^{0.1(100+l)}\right) - 100$$

were, n = measurement level number

l = average normalised L_{eq} *(for the PA system)* and normalised L_{eq} *(for the DJ monitor)*

Because the focus group is in the centre of the speaker array the average frequency response from this group is good platform from which to compare the responses at different positions. Because all the vales in each position have been normalised to their own relative maximums, by subtracting the focus group average values from the values at the each position the relative differences can be assessed directly. This subtraction process was applied to the values at all remaining positions.

Figure 3.4 – Diagram of the club displaying the broadband L_{Aeq} deviations from the common maximum at each measurement position

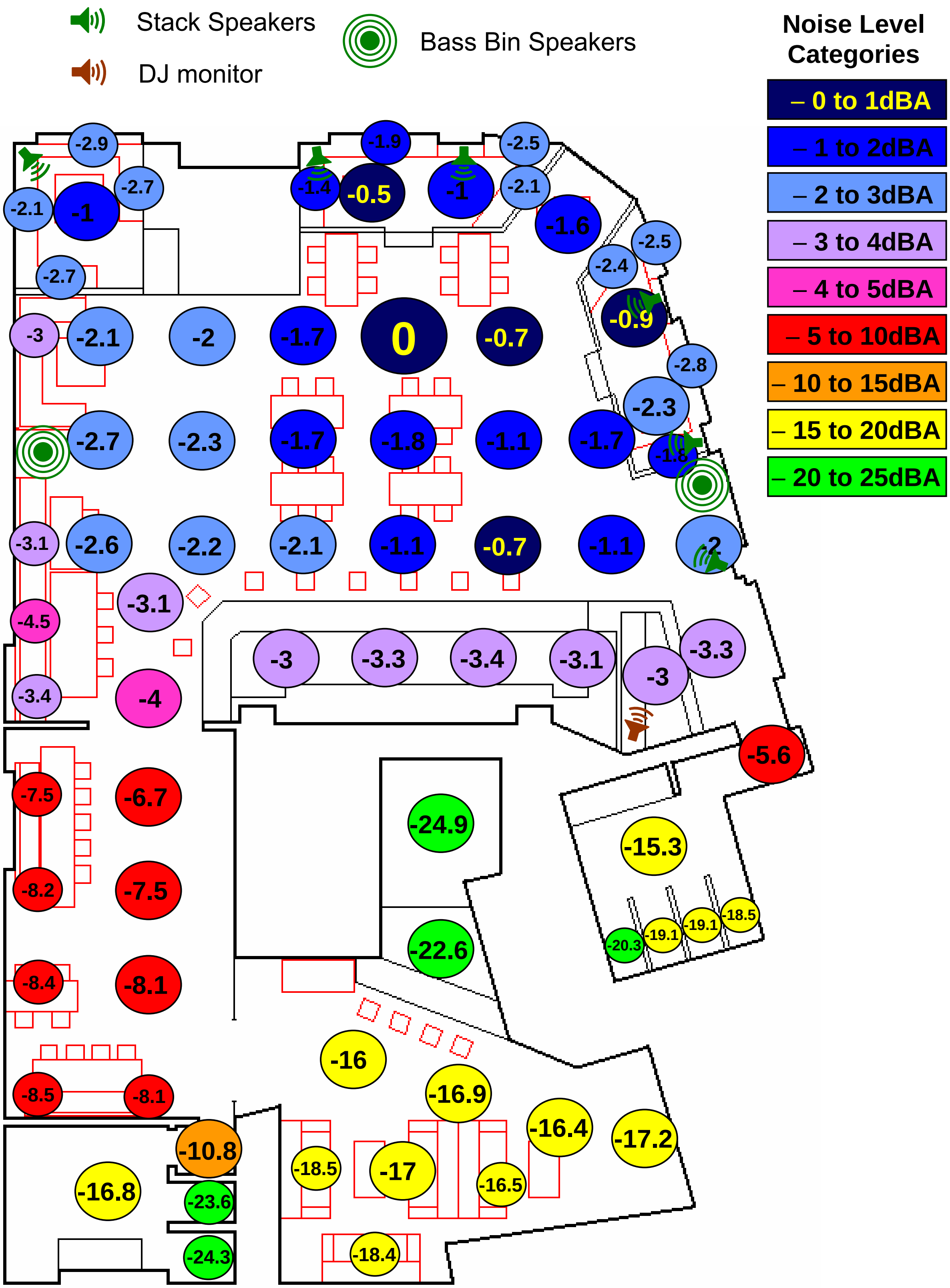


Figure 3.5 – 1/3 octave band normalised L_{eq} values measured in the focus group at an output level of 100dBA, logarithmic average and standard deviation

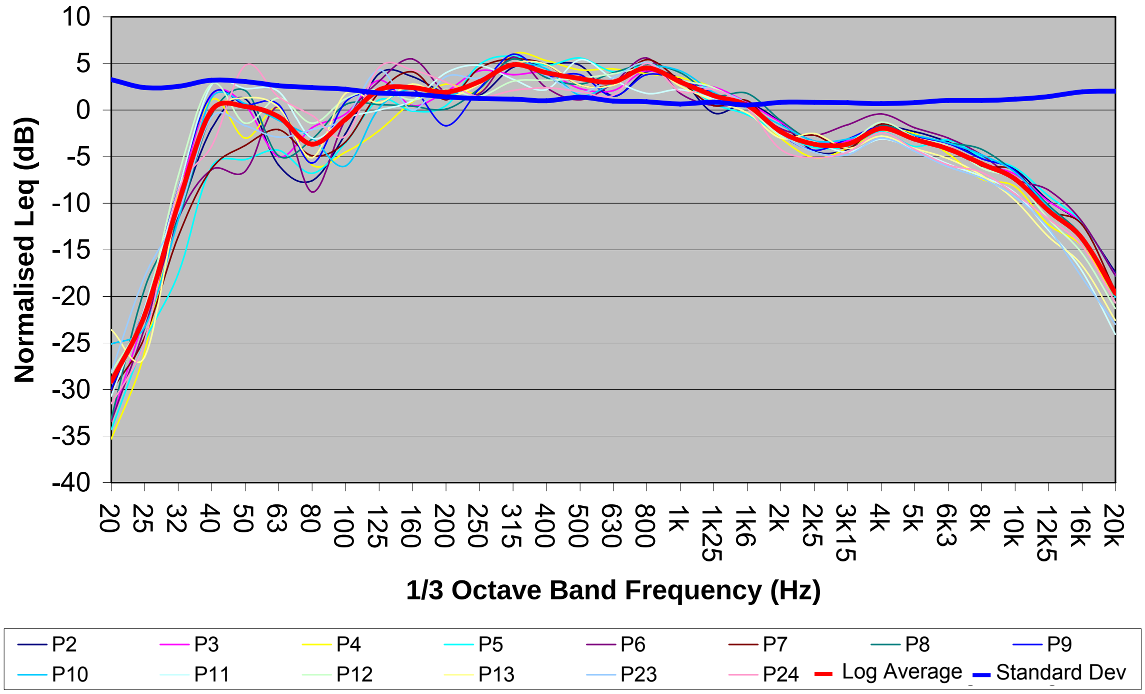


Figure 3.6 – 1/3 octave band normalised logarithmic averages of the focus group L_{eq} values at all measurement output levels

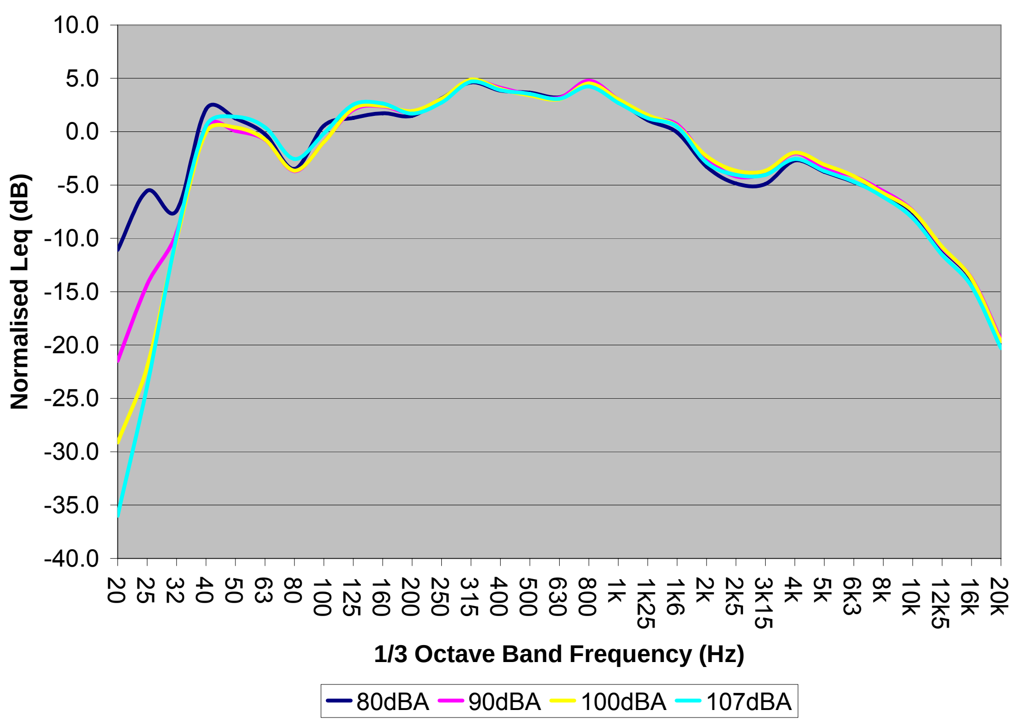


Figure 3.7 – 1/3 octave band Normalised L_{eq} measurements taken of the DJ monitor at all measurement output levels

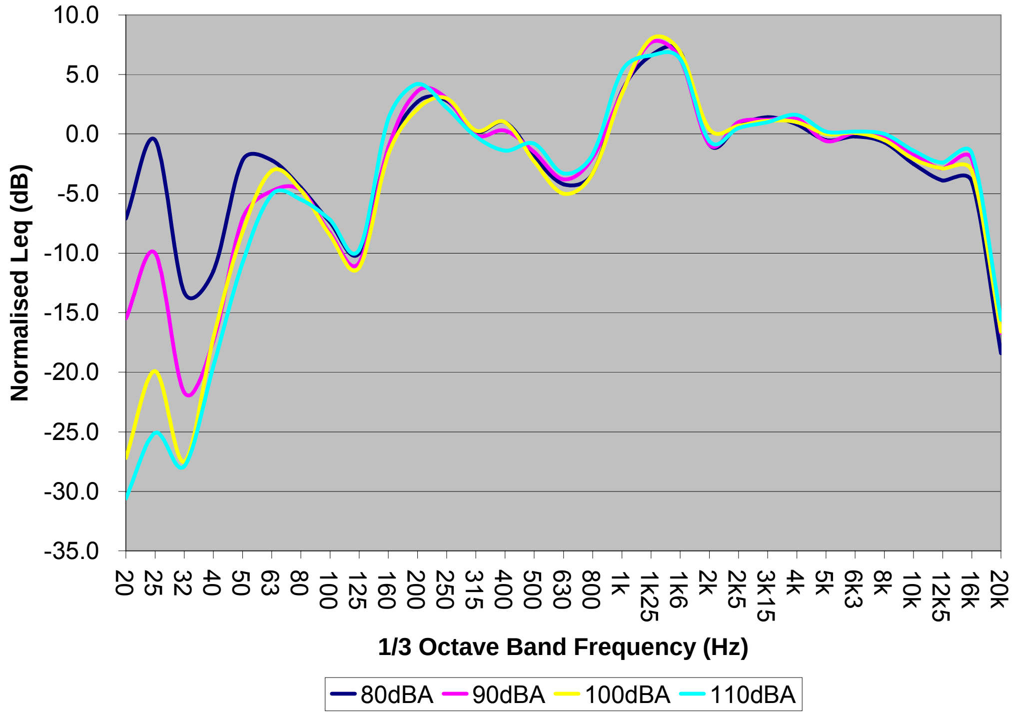


Figure 3.8 – 1/3 octave band L_{eq} normalised logarithmic averages of all measurement output levels for both the PA focus group and DJ monitor

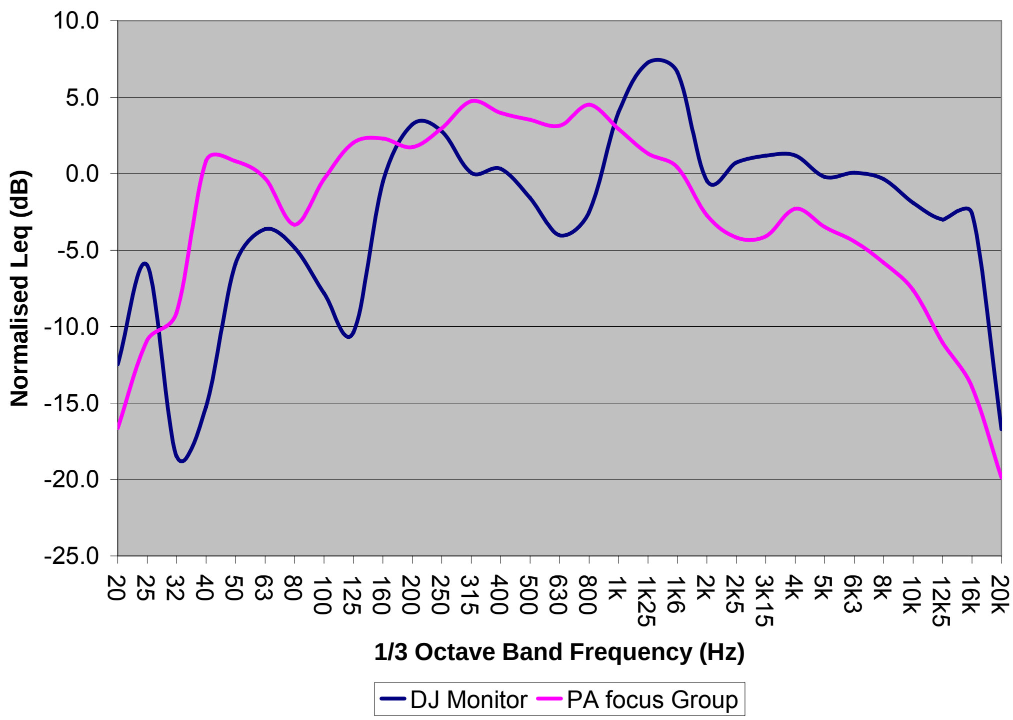


Figure 3.9 – 1/3 octave band L_{eq} measurements taken at positions 12 and 24 of the background noise floor and an output level of 100dBA

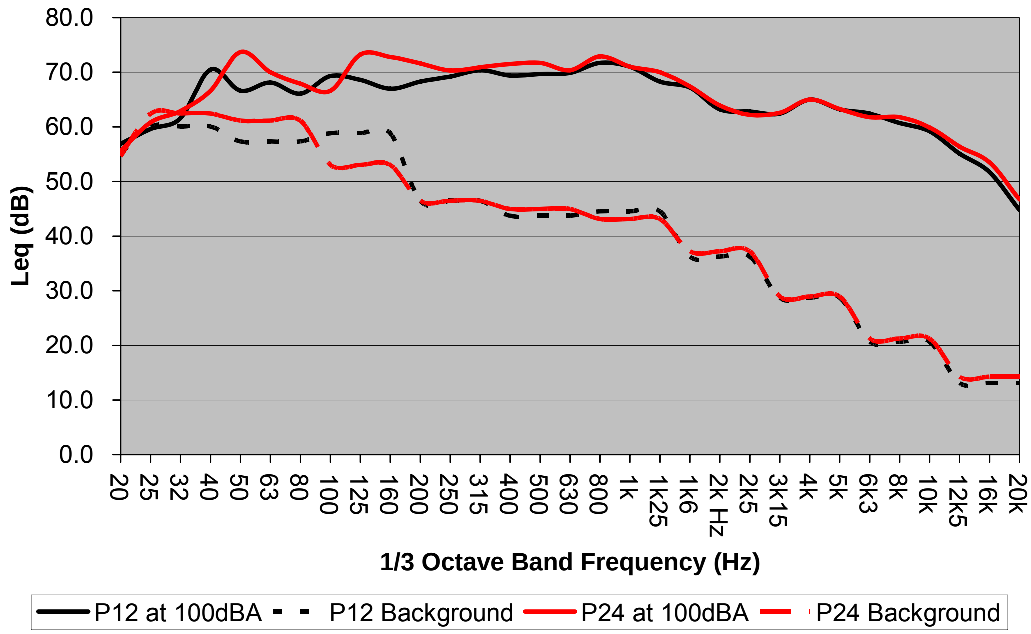


Figure 3.10 – 1/3 octave band deviations from the focus group average at positions behind the bar and in the DJ booth

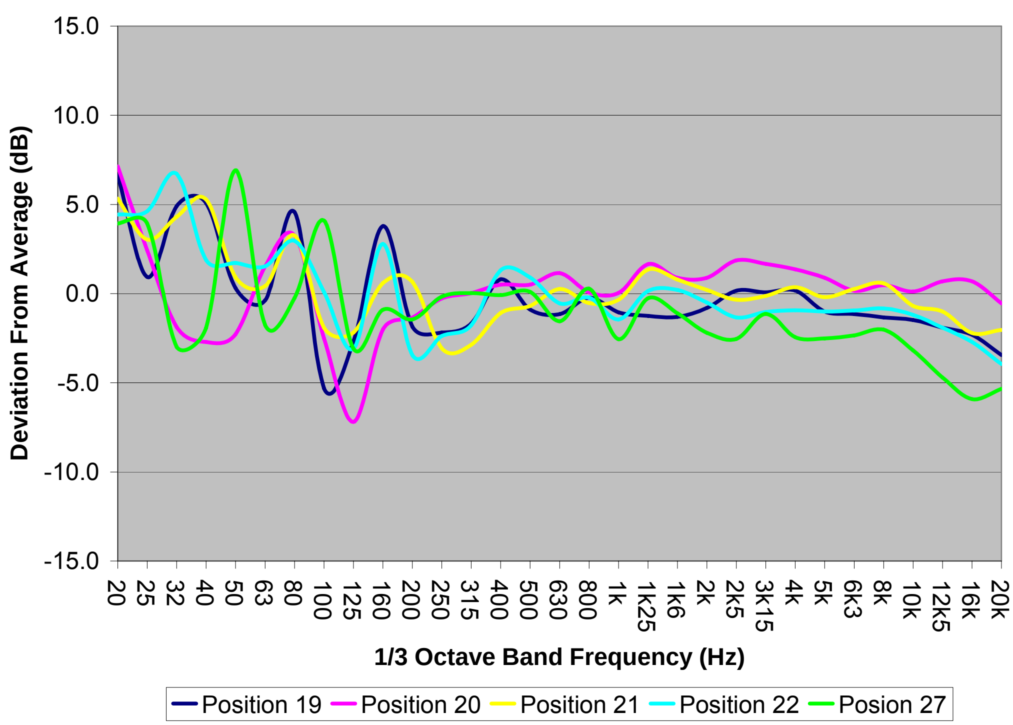


Figure 3.11 – 1/3 octave band deviations from the focus group average at positions in the first raised seating area

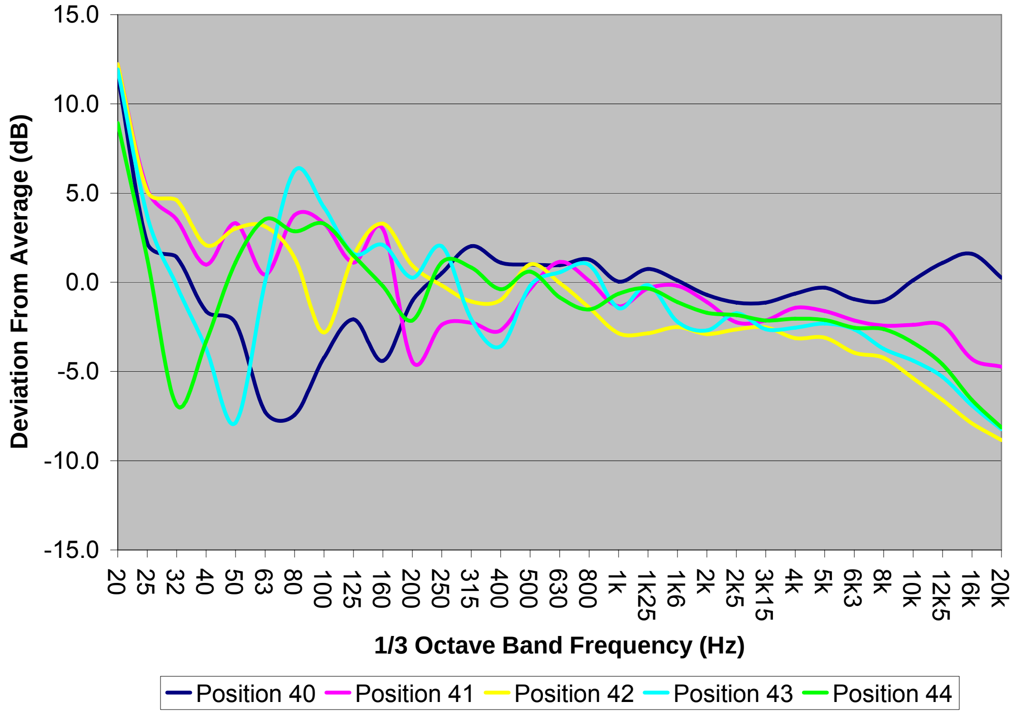


Figure 3.12 – 1/3 octave band deviations from the focus group average at positions in the second raised seating area

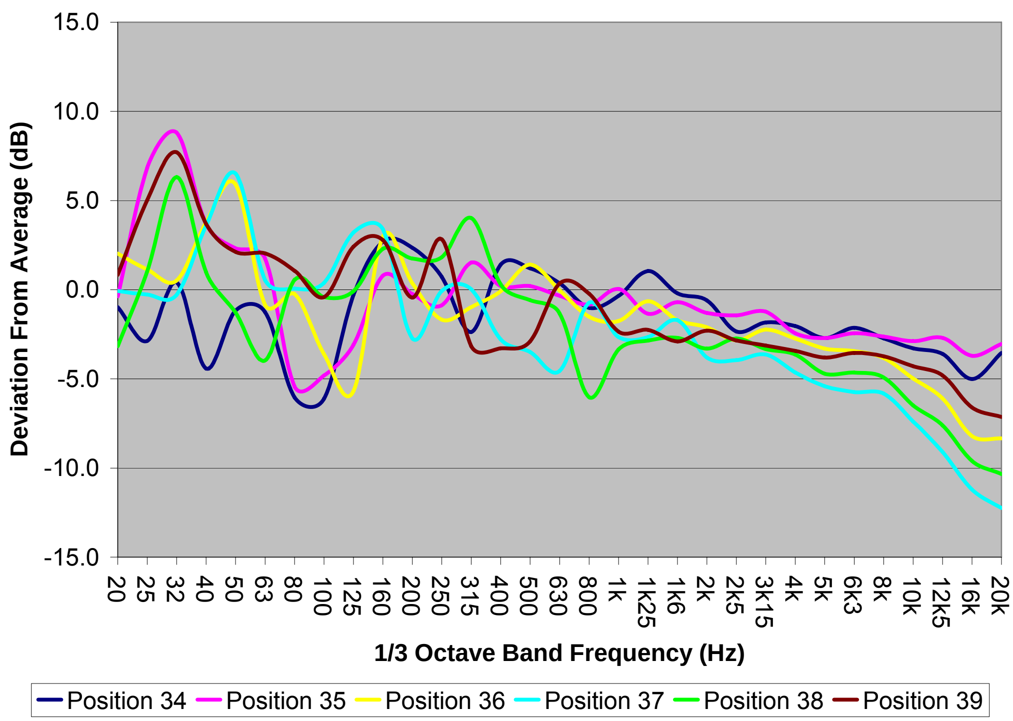


Figure 3.13 – 1/3 octave band deviations from the focus group average at positions in the third raised seating area

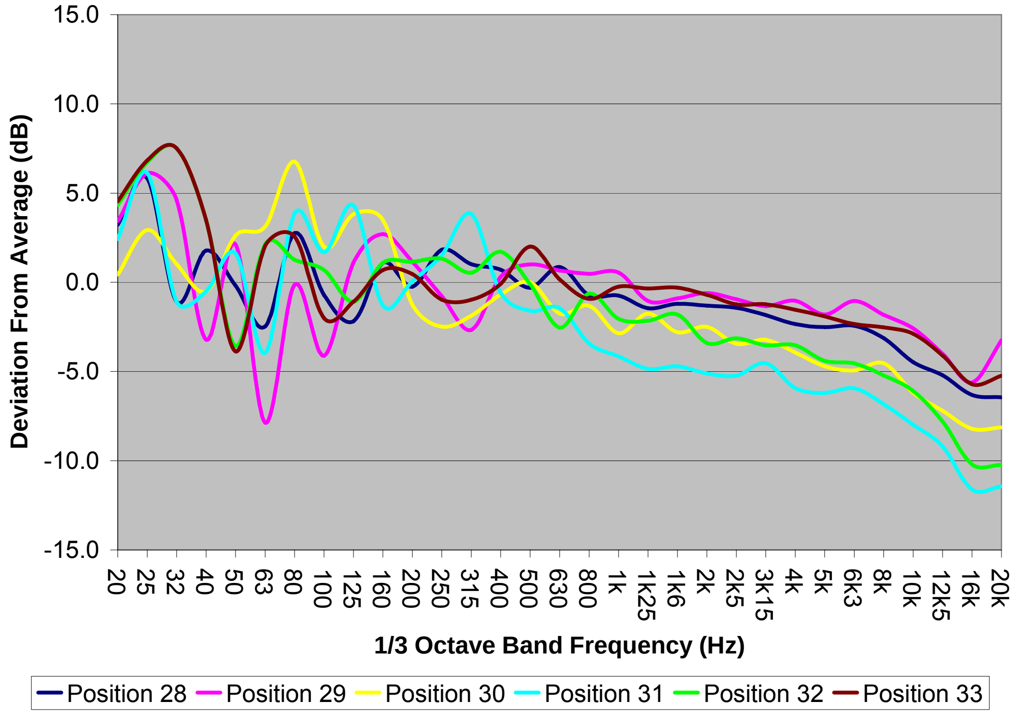


Figure 3.14 – 1/3 octave band deviations from the focus group average at seating positions in the main room along the west wall

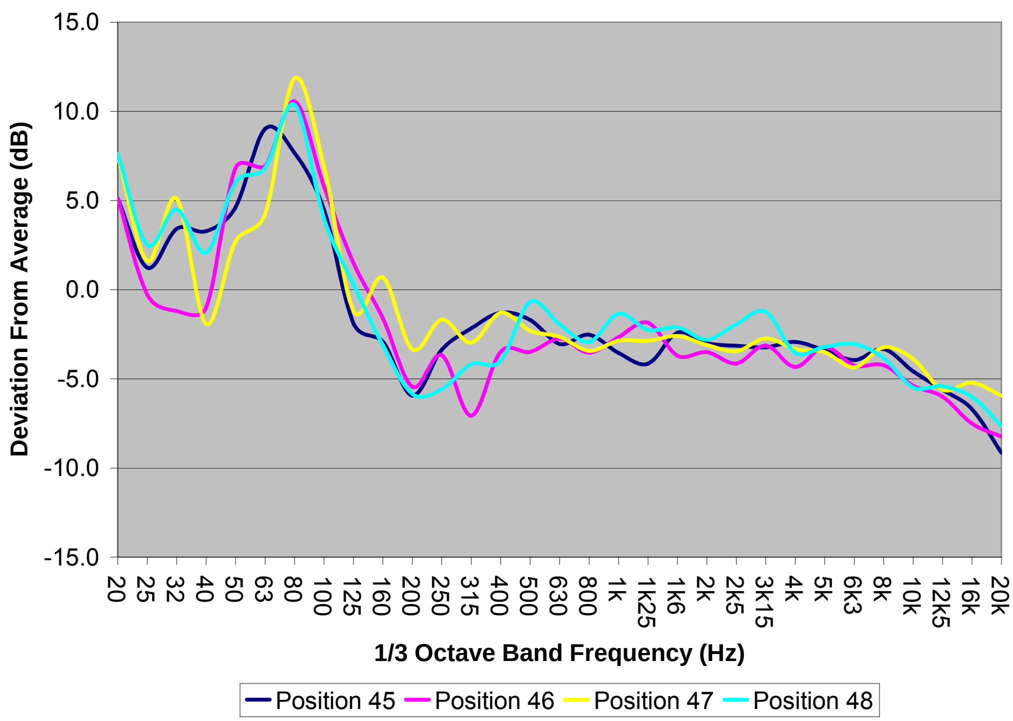


Figure 3.15 – 1/3 octave band deviations from the focus group average at standing positions between the main dance floor and the back room

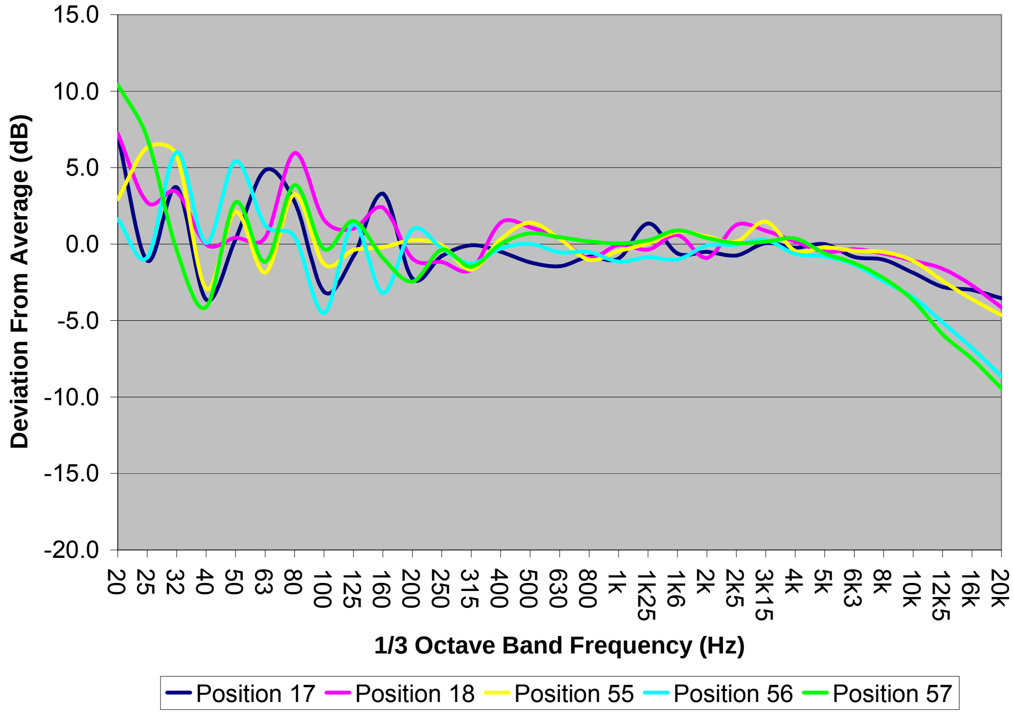


Figure 3.16 – 1/3 octave band deviations from the focus group average at seating positions in the middle room

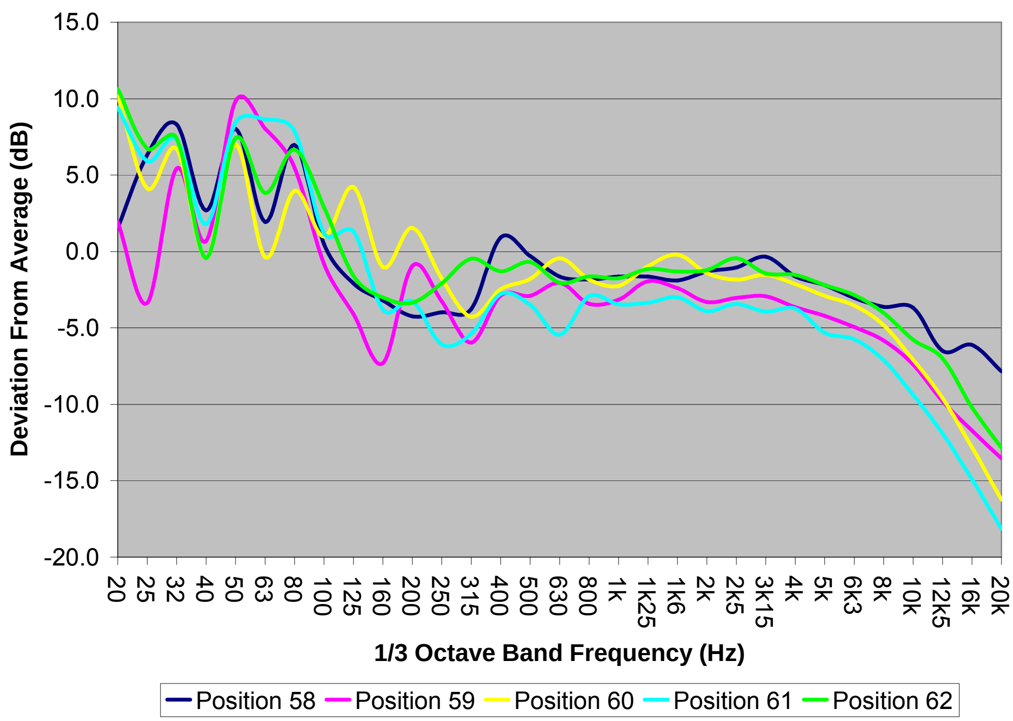


Figure 3.17 – 1/3 octave band deviations from the focus group average at seating positions in the back room

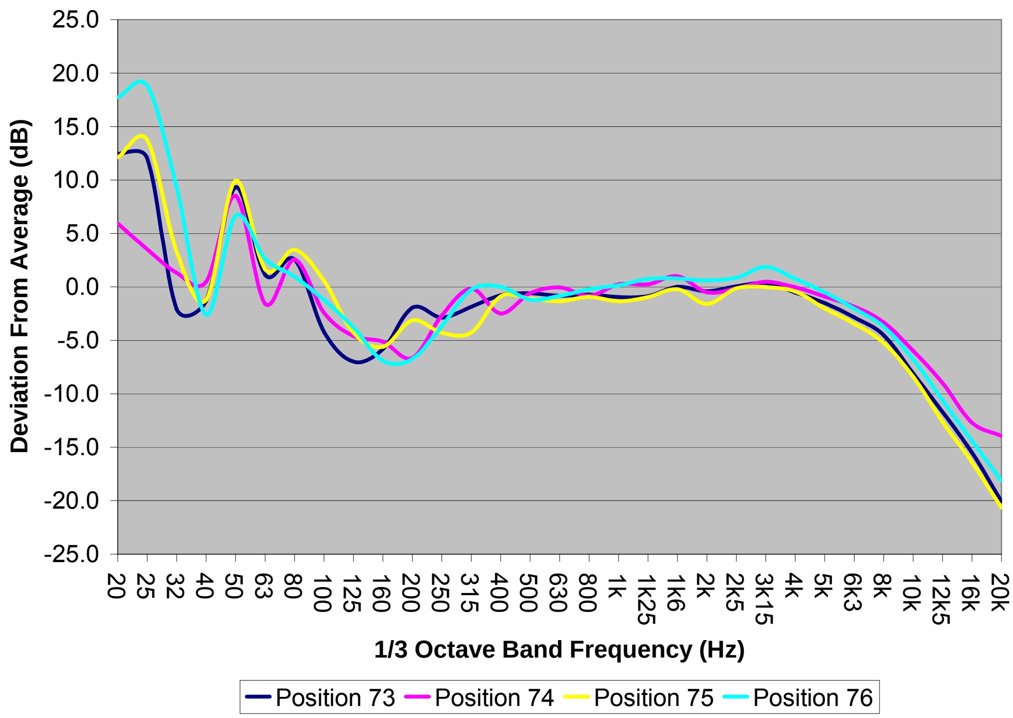


Figure 3.18 – 1/3 octave band deviations from the focus group average at standing positions in the back room and cloakroom

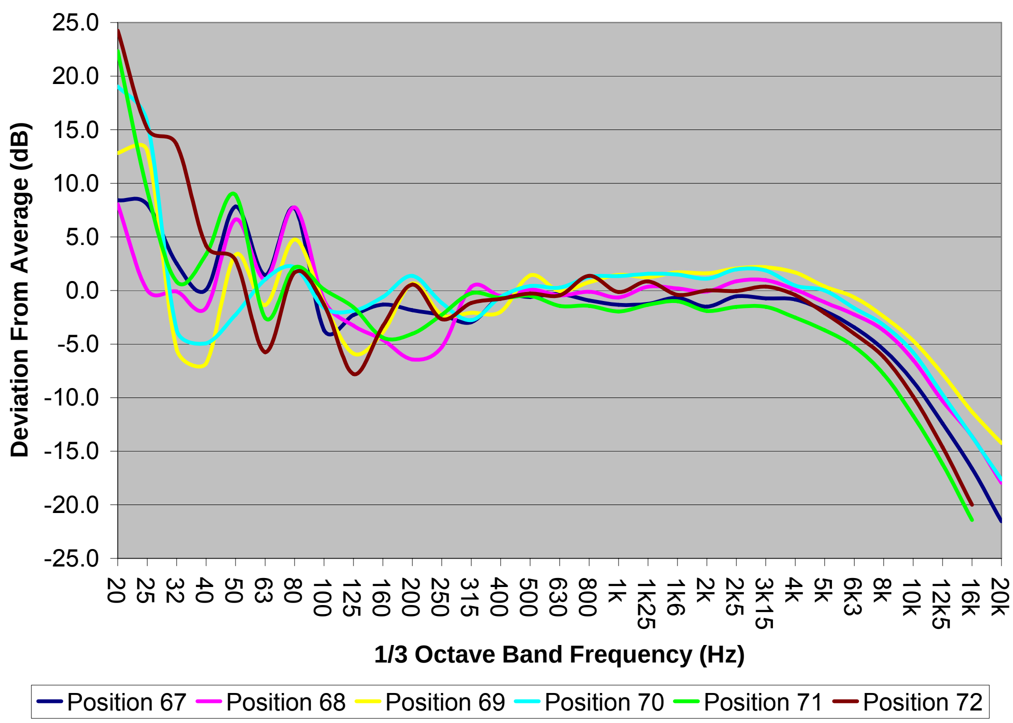


Figure 3.19 – 1/3 octave band deviations from the focus group average at positions in the ladies toilet

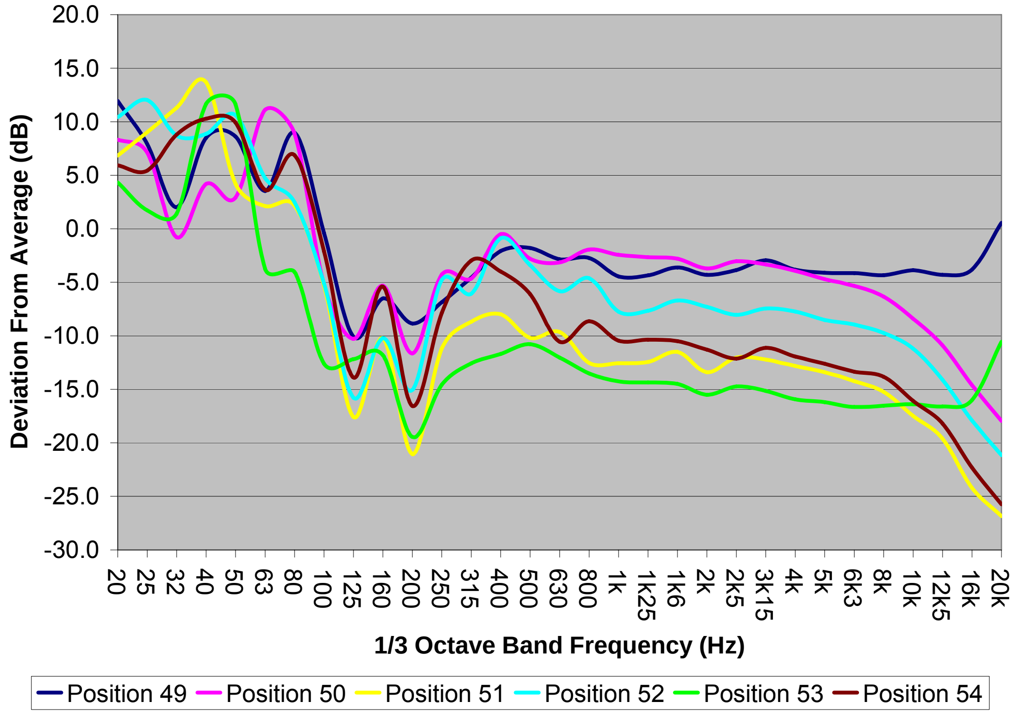
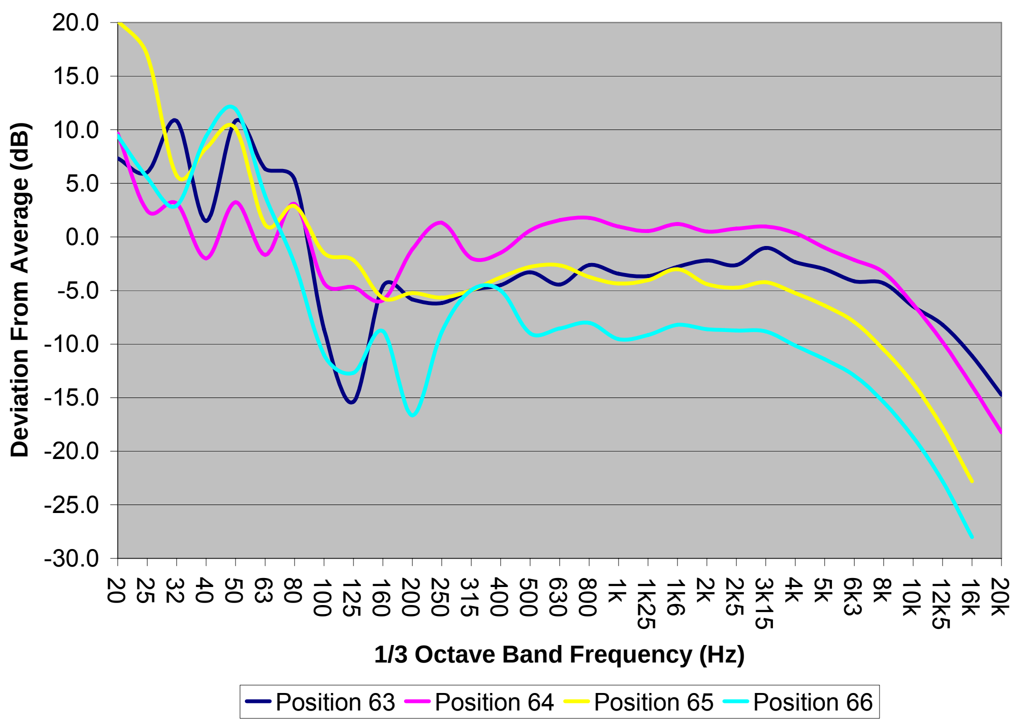


Figure 3.20 – 1/3 octave band deviations from the focus group average at positions in the men's toilet



3.5 – Analysis

Broadband Distribution

When assessing the broadband sound distribution throughout the club *(Figure 3.4)* in terms of the ideal requirements discussed in the introduction, the main room appears to do quite well. However, because of the utilisation of 1dB increments between the noise level categories up to 5dBA, the distribution of sound throughout the main room is described in much greater detail than for the rest of the club. As a consequence, the relative sound distribution in the main room can appear to be more significant than in actuality. It is important to remember that apart from at two positions, there is a differences of only 4dBA across the entire main room. When considering that the minimal audible change in sound level is generally considered to be 3dB[4], it is clear that a variation of only 4dB is relatively insignificant in terms of audible perception. However, it should be noted that in terms of the Directives discussed in section one, differences of 4dBA can be far more significant.

Even though the raised seating areas (see *Figure 1.2 Page 8* for definitions of specific areas) are closer to the loud speakers they are less noisy than the main dance floor and this can be attributed to several factors. The speakers are positioned well above the seating areas and are pointed towards the dance floor. Because of the output frequencies transmitted by these speaker they will be far more directional than the bass bins and leave an acoustic shadow when off axis at close proximities.

It is interesting to note that although the bass bins are far more omni-directional than the main stacks there effect on the surrounding sound field appears to be insignificant. The probable reason for this is because of the use of A-weighting and the relative insignificants it attributes to low frequency noise.

The central dance floor is the loudest area of the club as would be expected due to the fact that all the stack speakers are angled toward it. When moving away from dance floor and the stack speakers the sound levels gradually diminish with an approximate 3dBA drop in the back bar and west wall seating areas.

Because all the loudspeakers are located in the main room it is not surprising that there is a considerable sound level reduction in the middle and back rooms. By calculating the logarithmic average of all the values in each of these rooms the average sound reduction per room can be attained.

Equation 3.6

$$\overline{\text{Sound Reduction}}_{\text{in Middle Room}} = 10\log_{10}\frac{1}{8}\left(10^{\frac{7.5}{10}} + 10^{\frac{6.7}{10}} + 10^{\frac{8.2}{10}} + 10^{\frac{7.5}{10}} + 10^{\frac{8.4}{10}} + 10^{\frac{8.1}{10}} + 10^{\frac{8.5}{10}} + 10^{\frac{8.1}{10}}\right) = 7.9\text{dBA}$$

Equation 3.7

$$\overline{\text{Sound Reduction}}_{\text{in Back Room}} = 10\log_{10}\frac{1}{8}\left(10^{\frac{16}{10}} + 10^{\frac{16.9}{10}} + 10^{\frac{16.4}{10}} + 10^{\frac{17.2}{10}} + 10^{\frac{18.5}{10}} + 10^{\frac{17}{10}} + 10^{\frac{16.5}{10}} + 10^{\frac{18.4}{10}}\right) = 17.2\text{dBA}$$

Across the middle room there are differences in the sound field of approximately 1.4 dB and in the back room differences of approximately 2.5dB. However, by comparing the logarithmic averages it can be seen that the back room is a 9.7dB quieter than the middle room. The cause of this sudden reduction can be attributed to the relatively small opening between the rooms. It is generally accepted that a sound reduction of 10dB equates to a subjective reduction in loudness by a half**(5)** and so In terms of audibility, the average difference between the two rooms is very significant.

Some of the least noisy areas of the club are the toilets and this can again be attributed to the relatively small openings. However, considering that the ladies' toilet connects on to the main room it is surprising that the sound levels in the centres of each toilet are comparable. There are several possible causes that may contribute to this factor. The short corridor connecting the toilets to their adjoining rooms is longer in the ladies' and exhibits two angles of separation rather than the single angle in the men's. In addition, although not evident from the diagrams provided in the main body of the document, there are three large overhangs dropping from the ceiling at both ends and in the middle of ladies corridor area. This effectively creates a pair of expansion chambers between the toilet and main room. Expansion chambers are used as silencers in air ducts and work by reflecting sound energy back to towards the source cancelling out some of the sound energy(6).

Equalisation Strategy

Figure 3.5 displays a large quantity of data that is unsuitable for detailed analysis of individual values. However, this was not its purpose and has been included to provide a visual description of the relative commonalities between the frequency response curves across the focus group. This commonality is highlighted by the inclusion of the logarithmic average and the relative deviations from this average by the inclusion of the standard deviation. Between approximately 100Hz and 1.6KHz, there is an amplification and on either side of this bandwidth an attenuation for the majority of positions. From 40 to 20 Hz there is sudden decay in all the frequency response curve and although less steep, this is also evident from 4 to 20KHz.

The reasons for the differences between the individual frequency response curves in this group can be attributed to many factors. The most significant of these is the occurrence and relative effect of room modes. Room modes produce varying pressure zones and so a series of SPL measurements taken in a line travelling through one will exhibit pressure fluctuation at the modal frequency. Because the focus group is a grid layout of measurement positions covering a relatively large area, the occurrence of room modes will cause fluctuations between measurements.

It is in a reflective and none diffuse environment that room modes are generally most significant and because most of the surfaces in the club are flat with low absorption coefficients, this increase their significance. Although there are lots of tables, chairs, fixtures and fittings helping to create a diffuse sound field, at low frequencies these objects will be out of focus and insignificant. As a consequence and in general, the degree of room diffuseness is proportional to frequency. Because of this relationship the occurrence and effect of room modes to the effective frequency response at a particular position is also proportional to frequency.

An additional reason for the differences between the individual frequency response curves in the focus group can be attributed to the directionality of the speakers. The directionality of the loud speakers is proportional to frequency so at higher 1/3 octave bands, the effective frequency response will be dependent on the relative position of the measurement in relation to the speakers central line of axis. Therefore, at certain positions the values at higher frequencies will be greater than others

The effects of both of these factors are evident when looking at the standard deviation curve. At low frequencies it is at its highest because of room modes and than gradually decays until the effects of directionality become significant and it begins to rise again.

When comparing the differences between the focus group logarithmic averages and the DJ monitor response curves at the different output levels *(Figure 3.6 and 3.7),* it is clear that the most significant deviations occur at the very low frequencies. However, at very low frequencies these don't actually reflect differences between the effective frequency response curves, but are inconsistencies caused by the normalisation process. The noise floor is much more significant at low frequencies and up to 40Hz, just as significant as the measured signal as shown by *Figure 3.9*. Because at these frequencies there is effectively no output signal, independently of the measurement level, the values at these frequencies never change. As a consequence, the normalisation process will effectively offset any values that were constant at different output levels giving the impression of differences between the effective frequency response curves.

The differences at higher frequencies are far less significant and relatively consistent across the frequency range. These differences can be attributed to several factors but one of the most fundamental is that loudspeakers have different frequency characteristics at different output levels. This is because loudspeaker cones need to move further and faster when transmitting higher output levels which can excite different break-up modes *(flexibility and harmonic vibration of the cone material)*. Additional reasons include, that measurement positions might not have been perfectly aligned at different output levels, or that the L_{eq} periods at certain positions were insufficient and the noise levels hadn't properly stabilised.

By comparing the logarithmic averages of all output levels for both the PA focus group and the DJ monitor *(Figure 3.8),* it can be seen that the relative frequency reposes for each are quite different. The DJ monitor is far less stable than the PA system up to 2KHz with huge peaks and troughs. (It should be noted though that the PA system response curve in an average of 14 positions and this process effectively irons out erratic curvature.) After 4KHz the PA system curve drops off far more rapidly than the DJ monitor curve. However, because the PA measurements were taken in the far field, the absorption of air will have been far more significant than for the DJ monitor and will account for some of these losses.

Because the measurements taken of the DJ monitor were all at the same position at a very close proximity to the speaker, the reverberant sound field will have been far less significant than the direct sound field. Because of this, the effects of the building acoustics will not have significantly effected the frequency response curve and the measured distortions can mainly be attributed to the actual DJ monitor and its amplification system. It is far more difficult to quantify the degree in which the building acoustics effected the final PA focus group response curve. The only way this could be achieved accurately is if the output characteristics of the loudspeakers were assessed in an anechoic chamber.

To implement the equalisation strategy it would be necessary to invert the 1/3 octave band values from *Figure 3.7* and enter them into a pair of 1/3 octave band graphic equalisers integrated into the PA and DJ monitor amplification systems. Because the values have been normalised to zero they offer the smallest possible deviation from 0dB for the majority of the bands. As a consequence, the signal distortions inherent to all graphic equaliser systems would be minimised. However, when normalised in this manner very high amplification values are required at the highest and lowest frequencies. Because of this, the dynamic range of some equalisation systems may be insufficient to handle these values. In this instance the values could be biased to reduce the requires positive or negative headroom. To equalise the required positive and negative headroom the following formula could be utilised to calculate the correct bias value.

Equation 3.8

If $|\text{Maximum Value}| > |\text{Minimum Value}|$ then,

$$\text{Positive Bias} = \text{Maximum Value} - \left(\frac{\text{Maximum Value} - \text{Minimum Value}}{2}\right)$$

If $|\text{Maximum Value}| < |\text{Minimum Value}|$ then,

$$\text{Negative Bias} = \text{Minimum Value} - \left(\frac{\text{Maximum Value} - \text{Minimum Value}}{2}\right)$$

However, it should be noted that depending on the quality of the graphic equaliser system, it may be more advantageous to use the normalised values and simply attenuate the high and low end values to the systems dynamic range. Apart from the reasons of inherent signal distortion, it is questionable how efficient the bass bins are at frequencies below 32Hz and whether any of the customers can hear above 16KHz.

Given on the following page is a table of the final values that could be entered into a graphic equaliser to balance the PA system and DJ monitor. Two sets of results are given for both where the first provides the normalised values (N), and the second the biased values (B) equalising the required positive and negative headroom.

Table 3.1 – 1/3 octave band equalisation values that could be used to balance the PA system and DJ monitor

	PA System		DJ Monitor			PA System		DJ Monitor	
1/3 OBF (Hz)	**N**	**B**	**N**	**B**	**1/3 OBF (Hz)**	**N**	**B**	**N**	**B**
20	*16.6*	*9*	*12.5*	*6.9*	***800***	*-4.5*	*-12.1*	*2.5*	*-3.1*
25	*10.9*	*3.3*	*6*	*0.4*	***1K***	*-2.9*	*-10.5*	*-4*	*-9.6*
32	*9.1*	*1.5*	*18.5*	*12.9*	***1K25***	*-1.3*	*-8.9*	*-7.3*	*-12.9*
40	*-0.8*	*-8.4*	*15.2*	*9.6*	***1K6***	*-0.4*	*-8*	*-6.6*	*-12.2*
50	*-0.8*	*-8.4*	*5.9*	*0.3*	***2K***	*-2.7*	*-4.9*	*0.5*	*-5.1*
63	*0.3*	*-7.3*	*3.6*	*-2*	***2K15***	*4.2*	*-3.4*	*-0.7*	*-6.3*
80	*3.3*	*-4.3*	*4.8*	*-0.8*	***3K5***	*4.1*	*-3.5*	*-1.2*	*-6.8*
100	*0.3*	*-7.3*	*7.8*	*2.2*	***4K***	*2.3*	*-5.3*	*-1.2*	*-6.8*
125	*-2*	*-9.6*	*10.4*	*4.8*	***5K***	*3.5*	*-4.1*	*0.2*	*-5.4*
160	*-2.3*	*-9.9*	*0.5*	*-5.1*	***6K3***	*4.4*	*-3.2*	*-0.1*	*-5.7*
200	*-1.7*	*-9.3*	*-3.2*	*-8.8*	***8K***	*5.8*	*-1.8*	*0.4*	*-5.2*
250	*-3*	*-10.6*	*-2.8*	*-8.4*	***10***	*7.6*	*0*	*1.9*	*-3.7*
315	*-4.7*	*-12.3*	*-0.1*	*-5.7*	***12K5***	*11.1*	*3.5*	*3*	*-2.6*
400	*-4*	*-11.6*	*-0.3*	*-5.9*	***16K***	*14*	*6.4*	*2.6*	*-3*
500	*-3.3*	*-11.1*	*1.6*	*-4*	***20K***	*19.9*	*12.3*	*16.7*	*11.1*
630	*-3.1*	*-10.7*	*4*	*-1.6*					

It is important to note that this equalisation strategy has been based on measurements taken in an empty room. When the club is full of people the acoustic characteristics of the building will change due to their absorption and diffusion characteristics. It is beyond the scope of this document to analyse and account for these characteristics, but the current equalisation strategy would provide a level frequency response to work from.

Spectral Distribution

By studying the 1/3 octave band average deviations from all the positions around the club (Figures 3.10 to 3.20) it is clear that the bass frequency response is particularly uneven. As explained previously, these irregularities are caused by room modes. Ultimately, in a non-diffuse environment such as the club it is virtually impossible to have an balanced frequency response everywhere in the club. In addition, this is not helped by the fact all the loudspeakers are all localised in the main room.

By assessing the response curves from behind the bar *(Figure 3.10),* it can be seen that there is a general reduction at high frequencies on either side of the two central positions, 20 and 21. This may be caused by the position’s directional alignment with the two stack speakers on the north wall. In addition, positions 22 and 27 to the right of centre are well out of alignment with the stack speakers on the east wall, and position 19 to the right of centre is the furthest away. At low frequencies the response curves are generally all very different although there are some points of alignment at specific bands such as 80Hz.

In the first raised seating section *(Figure 3.11)* because of a high frequency acoustic shadow the positions with the lowest high frequency response, positions 42 and 43, are those furthest under the speaker. However, apart from position 40 in the centre at standing level, because the speaker is well above the seating areas, the differences between the high frequency response at different positions are minimal. The low frequency responses are all very different but at 20Hz, there is a universal and significant amplification. This may be due to the fact that all of these positions are in a corner of the main room. Although the pressure zones of all modes occur in the corners of a room, at very low frequencies the area of a single pressure zone is much greater and would cover the entire area. If several modes occur in this 1/3 octave band the overall frequency response at that band would be effectively amplified at all the positions.

In both the second and third raised setting areas *(Figures 3.12 and 3.13)* because of the high frequency acoustic shadow, the high frequency response is inversely proportional to the distance from the front of the stack speakers that are located on the walls above them. Again like the first raised seating section, there is little continuity between the bass frequency response at the various positions.

When assessing the seating positions along the west wall of the main room *(Figure 3.14)* it is clear that there is a significant amplification at 80Hz. An amplification at this frequency is also significant at many other positions throughout club but at positions along this west wall, including position 43 in the raised section, it is the predominant frequency of amplification. Because these positions are all very close to a large reflecting wall they have a much greater chance of being within the model pressure zones. Therefore, judging from this 80Hz amplification is very likely that a collection of modes within this band are present within the club.

At the positions travelling between the front and back rooms *(Figure 3.16),* the frequency response at the top end is inversely proportional to the distance from the main dance floor. This is caused because high frequency sound waves are scattered more efficiently and must effectively travel greater path lengths being absorbed by the air and on each reflection. Although there are few surfaces with high frequency absorption characteristics because the room is relatively large, the absorption of air becomes significant at higher frequencies.

At the lower frequencies in this group of positions a pattern is emerging that becomes more apparent in the middle room seating areas *(Figure 3.16)* and back room *(Figures 17 and 18)*. This pattern consists of effective amplifications at 80, 50 and 32Hz, and attenuations at 63 and 40Hz. The reason these patterns are beginning to emerge is because at greater distances from the sound source, the acoustic properties of the club become more significant.

The seating positions in the middle room *(Figure 3.16)* all exhibit a more base heavy response than the standing positions *(Figure 3.15).* This is because they are all close to the wall and have more chance of being within the pressure zones of the low frequency modes. As position 63 is located in the corner of the room it will be in the pressure zones of all the modes and this explains why it has the least significant high frequency response.

All the seating positions in the back room *(Figure 3.7,)* and the central standing positions (positions 67, 68 and 69; *Figure 3.18*) display relatively similar frequency response curves. The reason for this is because as the angles of the walls are all irregular and non-parallel, the sound field is likely to be much more diffuse reducing the occurrence of room modes. In addition, as the room is smaller, fewer significant low frequency modes can exist, and because its area is further from the sound source, it is harder to excite the ones that can. In all the back room positions there is a significant high frequency reduction and this can be attributed to the absorption of air due to the considerable distance from the sound source. The two positions in the cloakroom (Position 71 and 72) exhibit very high amplifications at the very lowest frequencies and conversely the greatest high frequency attenuations.

Nearly all of the positions in both the ladies' and the men's toilets *(Figures 3.19 and 3.20)* exhibit bass heavy frequency response curves. As well as the absorption of air at high frequencies, this can also be attributed to the effects of the hallway expansion chambers discussed previously and the fact that the wave path must turn several corners to enter the toilets. In both toilets, between approximately 100Hz and 350Hz there is an attenuation at many of the positions. This attenuation is also evident at all of the setting and many of the standing positions in the back room *(Figures 3.17 and 3.18)*. As both the toilets and the back room contain very similar types of suspended ceiling, this may be the cause of the attenuation.

3.6 – Conclusion

Even in the centre of the speaker array the effective frequency response of the PA system is far from balanced. There is an amplification between 100Hz and 1.6KHz peaking at around 5dB and significant attenuations on either side. There are also considerable differences between the respective output frequency responses of the DJ monitor and the PA system. The frequency response of the DJ monitor is very unstable at all frequencies below 2KHZ. However, from this frequency until 16KHz there is relative stability

The back bar area and all of the seating areas in the main room are quieter than the dance floor. However, across the entire main room there are level differences of only 4dB which is relatively insignificant in terms of audible perception.

Because of considerable differences between the low frequency response curves at positions that are relatively close together, It is clear that the room is not diffuse at these frequencies and that the effect of room modes on the output frequency response of the PA system is significant.

The implementation of the devised equalisation strategy would significantly improve and balance the effective frequency response of both the PA system and the DJ monitor. However, because of the problems associated with room modes, without acoustic treatment, there will always be significant variations in the low frequency response at different positions.

On average, the middle room provides a 7.9dB reduction in sound level to the loudest position in the club and the back room a 17.2dB reduction. However, because the PA system is localised in the main room, the frequency response curves in these rooms are bass heavy and lack high frequency definition.

Section 4 – MODELLING WITH CATT

4.1 – Introduction and Ideology

As discussed in the previous section, the effectiveness of the PA system is of great importance to the club in terms of customer satisfaction. In that section an equalisation strategy that could be used to optimise a balanced frequency distribution across the dance floor was developed. However, The definition or audio quality of the music distribution and/or acoustic environment can be quantified by many additional acoustic parameters such as *RT*, *EDT*, D_{50} / D_{80} and *STI* (see glossary of terms Page 11)

The significance of these more subtle perimeters to the hundreds of inebriated clubbers seeking out almost deafening levels of dance music is minimal. However, on some occasions the club is used for acoustic music performances, plays and poetry readings and for this kind of event, the relevance of these parameters is far more significant.

To devise a strategy that could be used to optimise all of these parameters and the sound distribution ideology discussed in section three would be very difficult. However, the development of such a strategy would include the quantity, type and positioning of the loud speakers, equalisation and acoustic treatment. An obvious planning tool for such a strategy would be an acoustic prediction model such as Catt and could be used to test architectural strategies, acoustic treatments, quantities, and positions of loud speaker systems. In addition, because the Catt application makes provisions for the industry standard formats for loudspeaker directionality, the limitations, advantages and disadvantages of specific loudspeaker manufacturers could also be assessed. Moreover, although limited to octave band analysis between 125Hz and 4KHz, the merits and requirements of an equalisation strategy could also be assessed.

Although hypothetically extremely useful, the effectiveness of an acoustic model is ultimately limited by the level of its prediction accuracy that is reasonably obtainable. The central aim of this section was to build a model and asses its prediction accuracy based on a comparison of a series or measured and predicted RTs. For continuity, the acoustic parameter RT30 was used throughout.

Because of the complex shape of the club, the environment as a whole is non-diffuse or non-Sabine. For this reason, the reverberation decay curve in such a space is unlikely to be entirely linear and this non-linearity may vary at different locations. Because reverberation time measurements attained from the linear predicted of a strait line approximation such as RT_{15} and RT_{30}, these measurements are meaningless in non-diffuse environments. For this reason, it should be noted that the measured and predicted RT_{30} values have been attained for purpose of comparison, and not of acoustic assessment.

4.2 – Instrumentation

Dell Latitude D610 fitted with a Digigram's VXPocket V2 sound card.

Omni-directional acoustic microphone. Earthworks M30BX. *Serial number n/a*

Omni directional Loud speaker. Bruel & Kjaer, model n/a . *Serial number n/a*

Power Amplifier. Audio SR707. *Serial number – 14961*

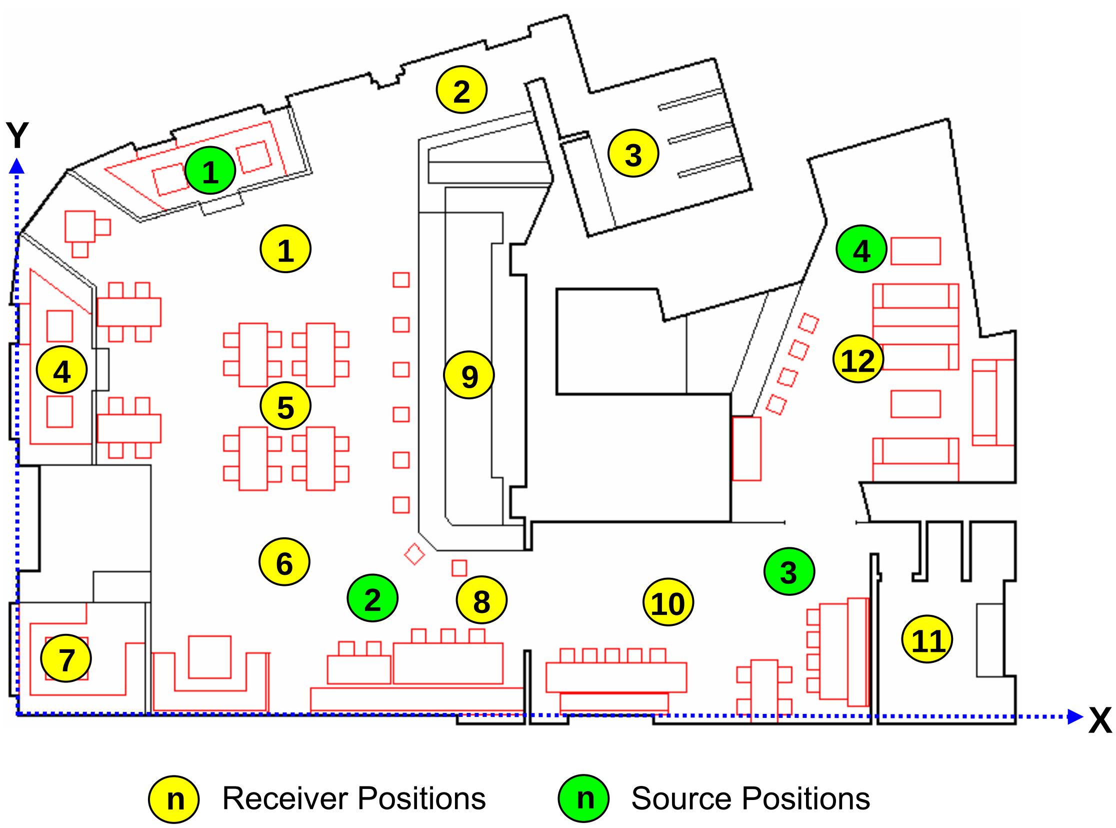
Software:

- WINMLS 2004. A software based measuring system
- CATT-Acoustic V 7.2. Ray-Acoustic modelling and prediction software

4.3 – Measurement Process Method and Procedure

This section of the document will be broken down in to a sequential step by step account of how and why the RT measurements were taken. In total forty eight measurements were taken comprising four source and twelve receiver positions. *Figure 4.1* displays the approximate source and receiver positions utilised for both measurements and predictions. The exact source and receiver coordinates have been included in the appendix *(Page 138)*.

Figure 4.1 - Plan diagram of the club displaying source and receiver positions



As mentioned previously, because the club is non-diffuse trying to calculate an average RT for the entire building would be meaningless. However, in the process of avoiding any near field or boundary effects some of the guidelines set out in British Standard[(7)] for measuring reverberation time were utilised. These included ensuring that the source and receivers were at least one meter away from the walls, large objects and each other.

The quantity and location of the receiver positions were selected so that an even spread of measurements could be analysed and compared across the entire club, without leaving any large areas un-measured. The quantity and locations of the source positions were selected so that there was at least one source position in each of the major rooms, and so that all areas of the club would be excited.

To take the measurements the WINMLS software based measurement system, an omni directional loudspeaker and an acoustic microphone were utilised. The WINMLS system was used because it enabled additional parameters to be measured that may be used for future research. The omni directional loud speaker was utilised in accordance with the relevant British Standard(7) for measuring reverberation time. It was also used because this kind of loud speaker is the simplest to model using the Catt software.

The measurements were taken in the daytime on a weekday when the club was not open to the public. However, throughout the duration of the measurement process there were between three and seven people present in the building. Because of the practicalities of the business (deliveries arriving, people moving things around), on some occasions measurements were taken with a background noise level that was more significant than the levels recorded.

> **Step 1**. The background noise levels were recorded in both the main and back rooms and the temperature from the digital thermostat controlling the air-conditioning was recorded.

A two minute L_{Aeq} measurement was used for this purpose in both rooms and an octave band two minute L_{eq} was also measured in the main room. The L_{Aeq} measurements were take for experimental completeness but the octave band L_{eq} was taken so that it could be programmed into the Catt applications environmental conditions. Because background noise makes no difference to RT prediction, for the purposes of this experiment, the background noise levels have not been included in the main body of the report. However, they have been included in the appendix *(Page X)* and were taken for purposes of future research.

Step 2. All of the receiver positions were chalked on to the floor.

Step 3. The sound source was placed in the first position.

Step 4. The output from the lap-top was connected to the amplifier and fed on to the sound source.

Step 5. The receiver was connected to the lap-top, fitted into a tripod and moved into the first position.

Figure 4.2 – Photo of the source and receiver placed in their first positions

Step 6. WINMLS was configured to measure and record the RTs using a swept sine or single sweep (SS) signal.

Figure 4.3 – Photo of the WINMLS configuration procedure

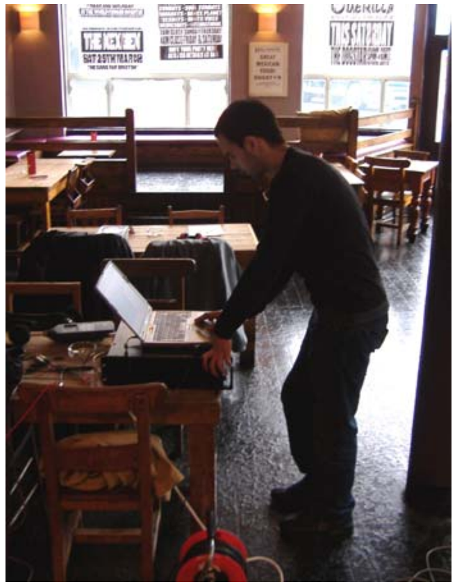
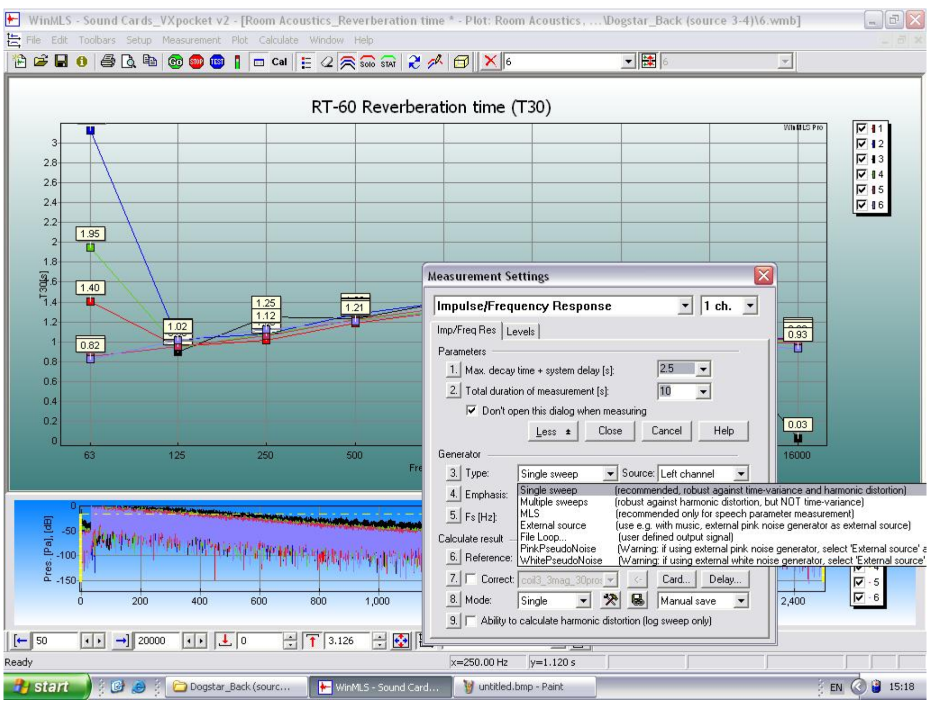


Figure 4.4 – Screen shot of the WINMLS configuration procedure



For RT measurements the choice of output signal is largely irrelevant. However, the reason the SS signal was implemented was because as well as RTs, additional acoustic parameters were also measured for possible further research and the software advised the use of this source signal fort those measurements.

Step 7. The receiver was moved to the remaining positions and measurements were taken at each.

Step 8. The source was moved to the remaining positions and steps 6 to 7 were repeated.

Step 9. The individual RT values were copied from WINMLS into a Microsoft Excel spread sheet for analysis and presentation purposes.

4.4 – Modelling Process Method and Procedure

Ideology

In building the model there were specific principles on which the methodology was governed. The most fundamental of these was that after completion, the model would not be adjusted or manipulated to compensate for differences between its predicted, and the measured data. The reason for this is because the objective was to create a model from accurate geometric data and reliable coefficient values but assess it solely on these merits.

The level of geometric detail incorporated in to the model was based on the concept that an object will effects a specific frequency when its size becomes comparable to the wavelength[8]. As the software makes predictions up to the 4KHz octave band, geometric details from approximately 8.5cm will effect the resultant data at this frequency. Although geometric detail on this scale would be effectively out of focus and insignificant for all other octave bands, it will not negatively effect the results at these lower frequencies.

Creating the Plans

Initially, it was hoped that the original building plans could be used as a basis for building the model. Unfortunately, after obtaining and studying these plans it was determined that because of countless renovations over many years, the plans bore little to no resemblance to the current layout. Because of this, it was necessary to create a new set of plans based on physical measurements of the club.

To begin this process a series of initial sketches were made and photographs taken. These sketches helped in the familiarisation with the clubs geometry and to determine what measurements would be necessary to establish an accurate plan with sufficient detail and accuracy.

On completion of these initial sketches a large number of measurements were taken around the club. The sketches, photographs and measurements were then used to create a series of detailed plans for the entire club incorporating all attributes to be modelled. This was a very time consuming process and required a great deal of readjustment and additional measurements to complete. All of these plans were scanned into a computer and have been included in the appendix *(Pages 111 - 110)*.

Modelling concepts

Because of the complexity of the modelling process a detailed explanation of the procedure is beyond the scope of this document. However, an outline to the process will be provided incorporating the basic modelling concepts. For more details about the modelling process see the Catt user manual.

All of the geometric data is programmed in to the model in the form of corner IDs and Plane IDs. A Corner ID is a point within a three dimensional space with a location defined with rectangular geometry using three coordinates, i.e. *X, Y, Z*. A Plane ID is an area of surface defined by a minimum of three corner IDs. The entire model is then built by connecting a series of planes together and assigning absorption and diffusion coefficients to each.

All of this geometric and coefficient data is inputted to the model in the form of GEO files. It is possible to include all of the required data in a single GEO file but for more complex models, it is easer to create several GEO files each containing the data for different areas.

The source and receiver data is entered in the form of LOC files. Up to a hundred receivers can be used at any one time and the software also enables the use of multiple, and simultaneous sources. The source data must include location coordinates, directionality information and octave band SPLs. The receiver data simply includes location coordinates.

Creating the Model

Before using the plans to help define the various Corner and Plane IDs the clubs geometry was divided into interconnecting sections that would be suitable as individual GEO files. Because the main room is the largest and contains the most complicated geometry, twelve individual GEO files were utilised. The remaining rooms were much smaller and simpler in terms of geometric detail and so only one GEO file was used for each.

One of the difficulties using Catt is defining planes that are not in line with either of the three rectangular axis. The reason for this is because a plane must be made up from a series of Corner IDs that are all perfectly inline with one another in a specific direction. If that direction is not inline with any of the axial directions the coordinates for each Corner ID must be accurately calculated using trigonometric calculations.

Because there are many surfaces in the club that out of line with an axis the process of building the model required hundreds of these calculations. The software makes some provisions for this problem by allowing one of a Corner ID coordinates to be locked to another plane. This function was used on numerous occasions and was helpful but the software would benefit significantly if a polar coordinate system could be integrated into the existing system.

Throughout the club there are many tables, chairs, pews, barstools and sofas and they were all modelled with relative accuracy. Each of these objects were assigned an individual GEO file to make use of the Object Function in Catt. This function allows an object to be moved anywhere within the model and rotated around its own independent set of axis. Because many of these objects were identical, e.g. the chairs, barstools, some of the tables, etc, it was possible to save time by copying many of the Object GEO files and moving them to the correct positions. In total, eighty three individual Object GEO files were utilised but because of the coping process, only fourteen independent sets of geometry data needed to be derived.

Because of the volume and length of GEO files used in the model's construction it has not been possible to include a paper copy of them in the appendix. However, the entire Catt model including all GEO and LOC files has been burnt on to CD and attached in the appendix.

As well as generating all the individual Corner and Plane IDs it was necessary to assign each Plane ID with a set of octave band absorption and diffusion coefficients.
It was determined that in total, nineteen sets of coefficient data could be used to describe the entire club and have been provided in *Table 3.1*. The majority of the absorption coefficient values were taken from reliable databases and have been referenced accordingly. However, there are virtually no reliable databases for diffusion coefficients and these values were derived through advise given in the Catt help files and an understanding of the properties of diffusion.

The methodology used to derive these values was based on considering the relative proportionality of a surface roughness in comparison to the wavelength of the relevant frequency. The Catt help files recommend that all average sized flat surfaces should be assigned a minimum of 20% diffusion across the octave bands and that if in doubt, it is better to over assign diffusion coefficients(9).

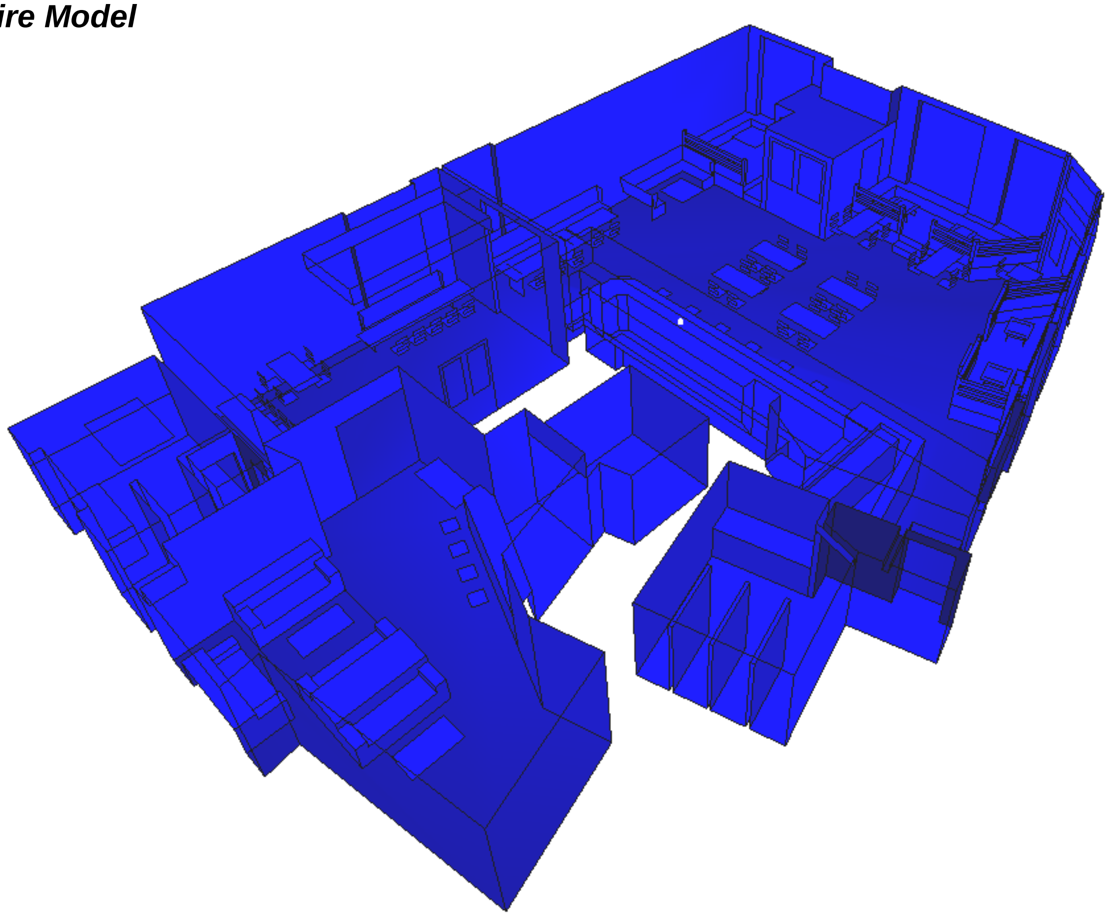
Table 4.1 – Absorption and Diffusion Coefficients used for the model

	Absorption Coefficients							Diffusion Coefficients					
Surface Description	125	250	500	1K	2K	4K	**Ref**	125	250	500	1K	2K	4K
Wood 25mm with air space	19	14	9	6	6	5	10	20	20	20	30	30	30
Wooden floor on joists	15	11	10	7	6	7	10	10	10	20	30	30	30
Plywood panelling 1cm thick	28	22	17	9	10	11	11	20	20	20	30	30	30
Thin plywood panelling	42	21	10	8	6	6	10	20	20	20	30	30	30
Solid wood polished	10	7	5	5	4	4	12	20	20	20	30	30	30
Textured wood break	10	7	5	5	4	4	*	20	20	20	30	40	70
Wood chair	2	3	4	7	7	7	13	20	30	50	70	80	90
Plasterboard on frame – 100mm empty cavity	8	11	5	3	2	3	10	20	20	20	30	30	30
1.5” seat cushion	20	30	34	34	32	28	12	20	20	30	30	30	30
Sofa cushion	30	40	46	46	40	35	14	20	20	30	30	30	40
Smooth ceramic tiles	1	1	1	2	2	2	11	20	20	20	30	30	30
Double glazing 2-3mm thick >30mm gap	15	5	3	3	2	2	13	20	20	20	20	20	20
Ordinary window glass	35	25	18	12	7	4	13	20	20	20	20	20	20
Plastered and painted brickwork	1	2	2	3	3	4	14	10	10	20	20	20	20
Concrete floor	1	1	2	2	2	2	14	20	20	20	20	20	20
Tile on concrete	2	3	3	3	3	2	11	20	20	20	20	20	20
Plasterboard ceiling on battens With air space above	20	14	10	8	4	2	11	20	20	30	30	30	30
Glass bottles	20	20	20	20	20	20	*	20	20	30	40	50	60
LPs, wires, DJ decks on plywood	28	22	17	9	10	11	*	20	30	40	50	60	70

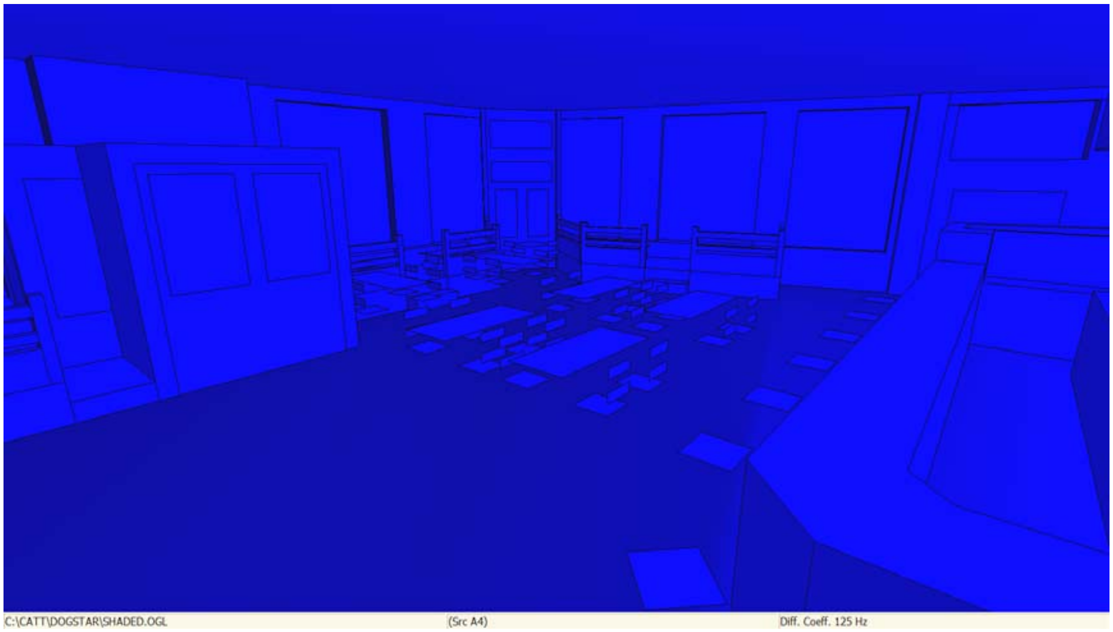
Where a star has been inserted in the reference column the absorption coefficients were devised independently because no match for the surface description could be found. The textured wood break was essentially a polished wood but with an unusual surface texture accounted for with the ascribed diffusion coefficients. The high values used for the glass bottles were derived because of the findings from an experiment at the Riverbank Acoustical Laboratories(15). The experiment was undertaken to measure the absorption of a tight array of empty bottles. The results suggested that the bottles working as cavity absorbers were very efficient at their resonant frequency of approximately 200Hz. Because the bottles in the bar are all different sizes with various quantities of fluid in each, a relatively high but uniform value was ascribed. The absorption coefficient values assigned to the LPs, wires, etc, were copied across from the plywood coefficients because for that area, plywood was the most prominent surface.

Figure 4.5 – Screen shots of the completed model taken from the 3D viewer

Entire Model



Main Room



Using the model

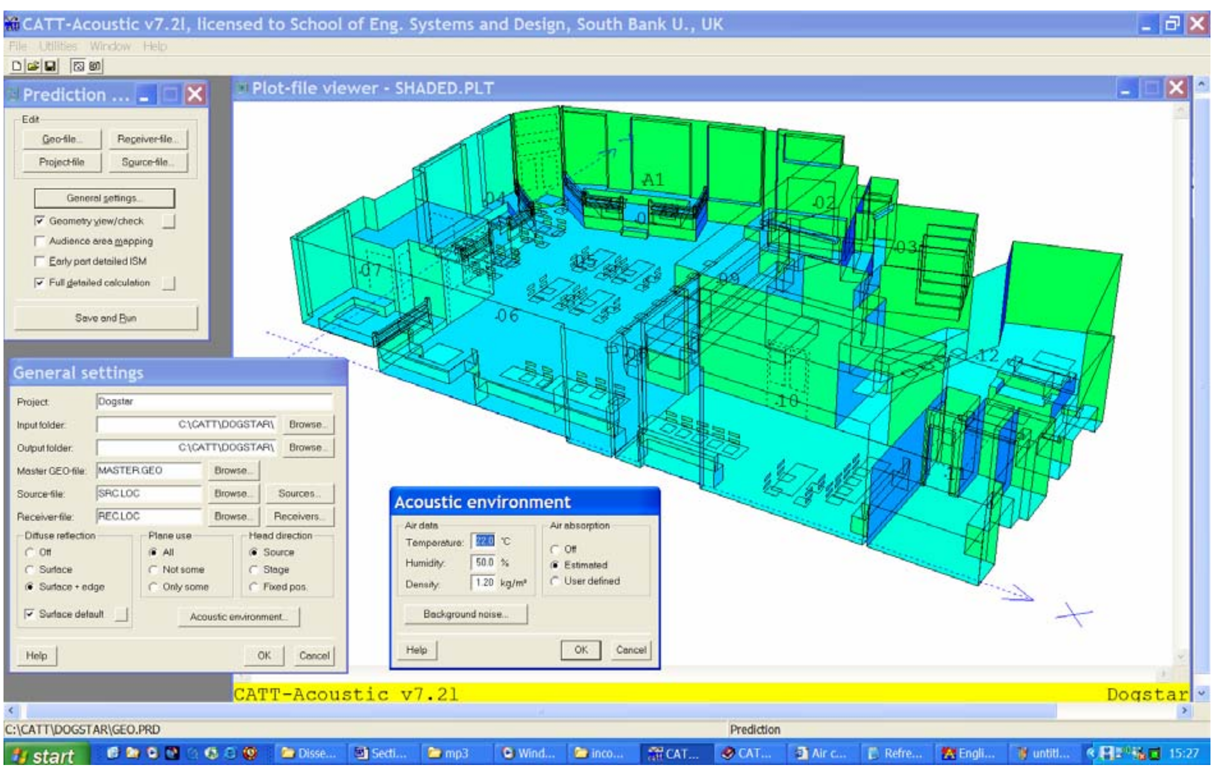
Before the model could be used it was necessary to set up a series of parameters and the source and receivers LOC files. One LOC file was used to input the coordinates for all twelve receiver positions and another to input the four source positions. All source and receiver positions were placed in the same locations as for the actual measurements and as mentioned previously, these coordinates have been included in the appendix *(Page 138)*.

The temperature reading (22°C) taken at the time of the experiment was inputted in to the models environmental settings. However, as mentioned previously, because for RT prediction background noise levels are irrelevant, the values taken at the time of the experiment were not set up. In the environmental settings the model also asks for air humidity and density values and whether air absorption should be estimated or user defined. Apart from the temperature the default values of 50% humidity, 1.2kg/m³ air density and estimated air absorption were selected.

To attain the predicted results necessary to compare with the measured results a run cycle was completed for each of the four source positions. The approximate run time for each run cycle was forty minutes. The computer used for the modelling process employed a 1700MHz Intel(R) Pentium(R) M processor with 512MB of 592MHz ram.

The estimated air absorption process is governed by the assigned temperature and humidity variables and their value can make a significant impact on the RT predictions at the higher octave bands. Air conditioning and refrigeration units reduce humidity levels(16) and because of a large array of refrigerators in the club and active air-conditioning at the time of the experiment, it is likely that the air humidity levels may have been lower than the Catt default value. Because the actual humidity value at the time of the experiment was an unknown quantity, predictions were made with a series of reduced humidity values for analysis. These predictions were made with humidity values of ten, twenty, thirty and forty present. Because these predictions were only made for purposes of speculative observation, the predictions were only made at a single source and receiver position, S1and R1 (See *Figure 3.2*).

Figure 4.6 – Screen shot of the Catt modelling software



4.5 – Results

For purposes of assessing the accuracy of the predicted results the following average error formula was utilised for results in each source group and to calculate a total error value for all the results.

Equation - 4.1

$$\overline{\%\,\text{Error}} = \left(\frac{\sum_{1}^{n} \left| \text{Predicted Values} - \text{Measured Values} \right|}{\text{n}} \right) \times \left(\frac{\sum_{1}^{n} \text{Measured Values}}{\text{n}} \right) 100^{-1}$$

where, n = number of measurements taken

Figures 4.7 to 4.10 – Measured and Predicted Octave Band Reverberation Times at Source Position S1

Figure 4.7 - Measured at R1 - R6

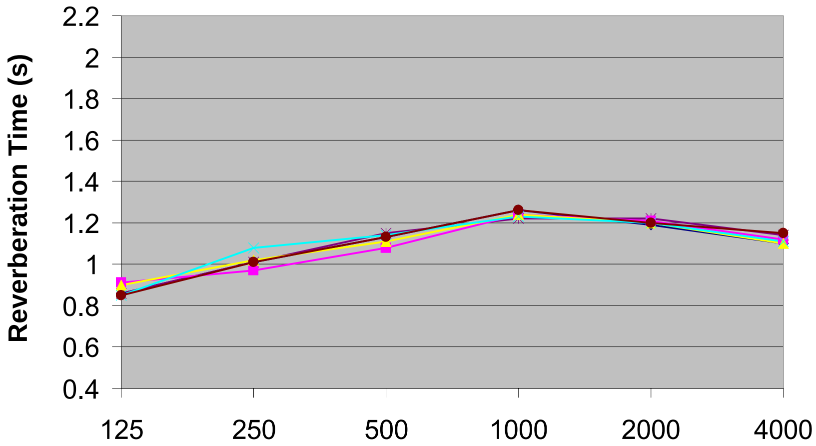
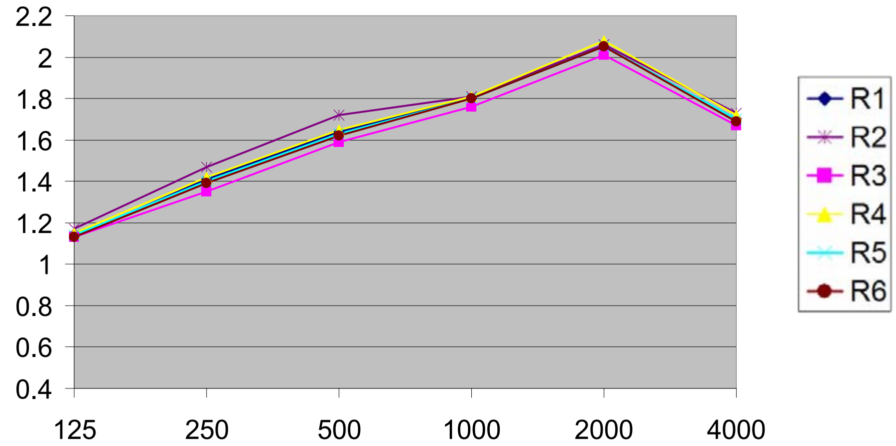


Figure 4.8 - Predicted at R1- R6



Octave Band Frequency (Hz)

Figure 4.9 - Measured at R7 - R12

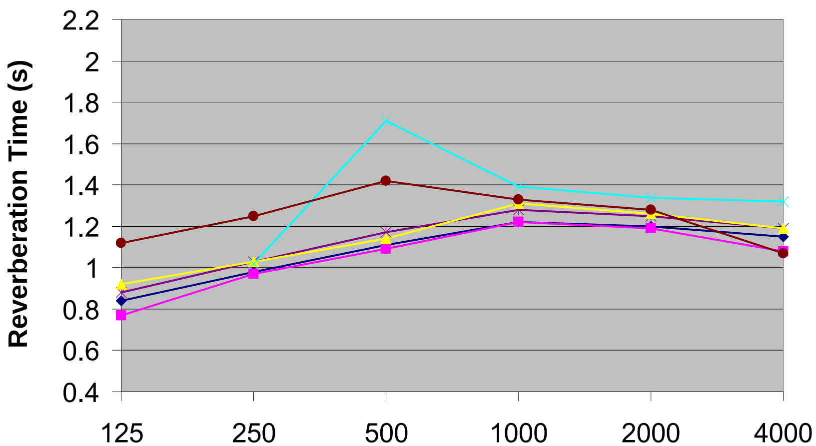
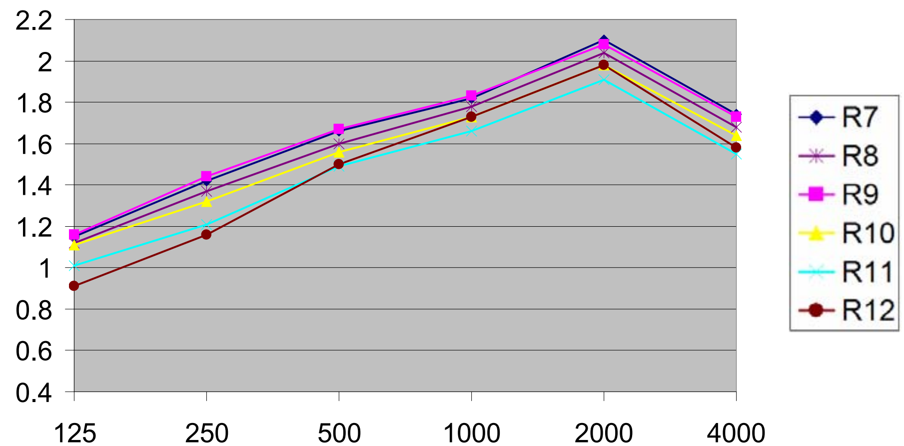


Figure 4.10 –Predicted at R7 - R12



Octave Band Frequency (Hz)

Figures 4.11 to 4.13 – Measured and Predicted Octave Band Reverberation Times at Source Position S2

Figure 4.11 - Measured at R1 - R6

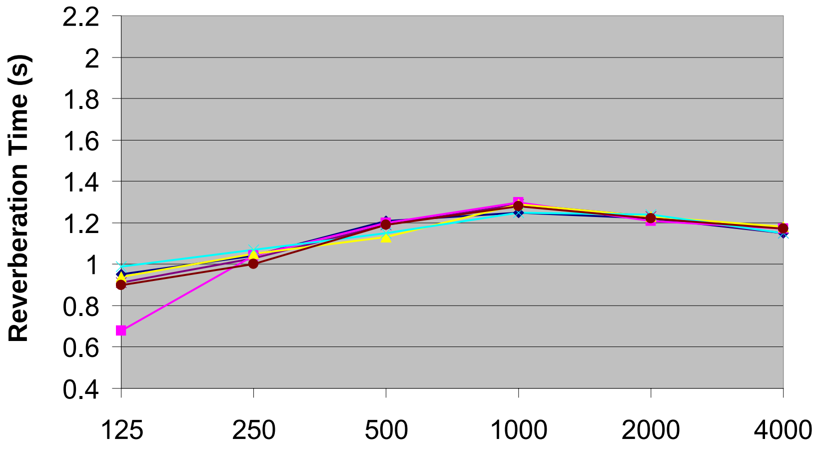
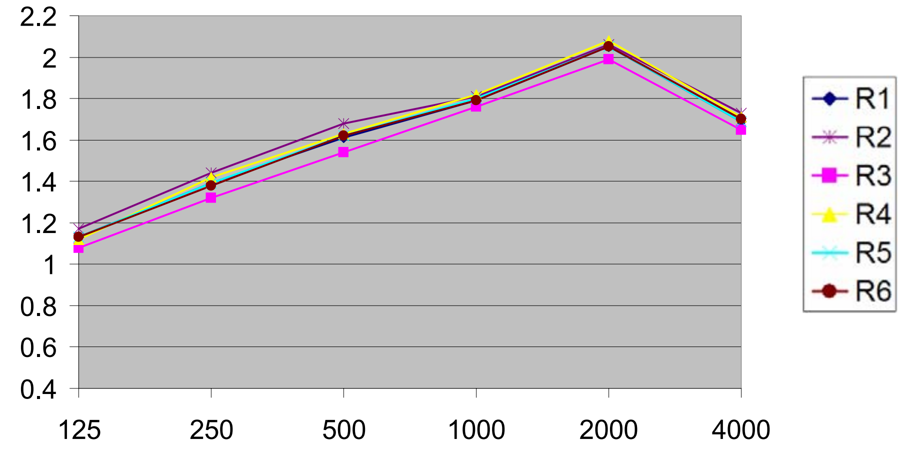


Figure 4.12 - Predicted at R1- R6



Octave Band Frequency (Hz)

Figure 4.13 - Measured at R7 - R12

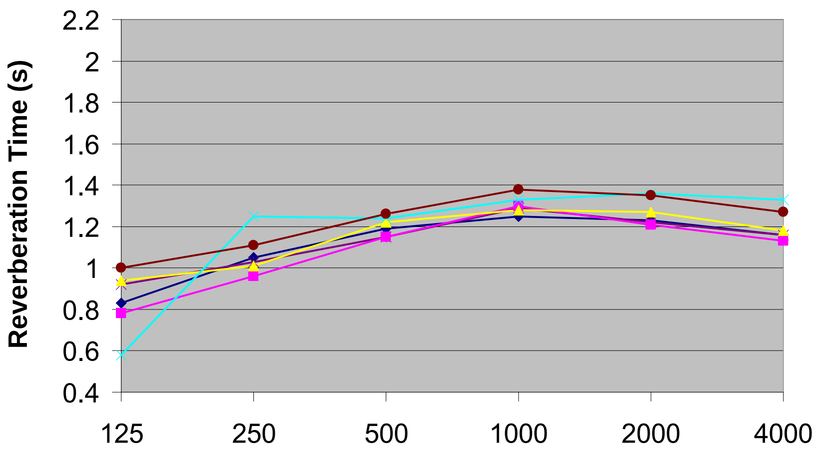
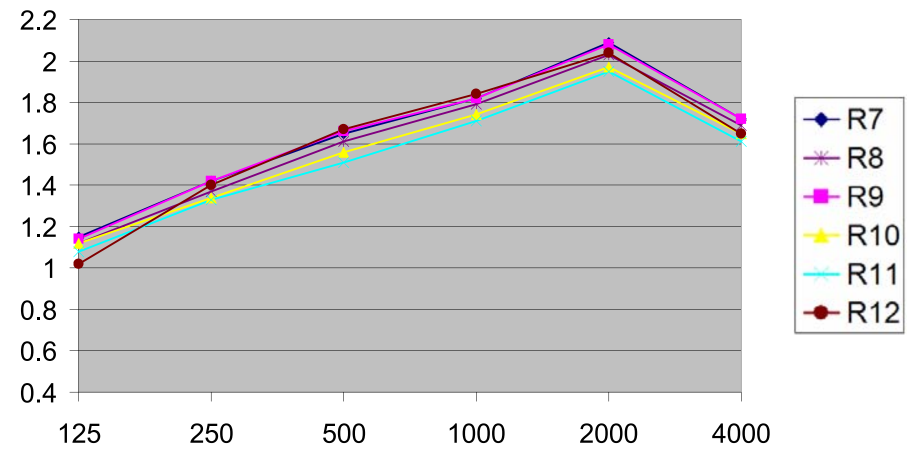


Figure 4.14 –Predicted at R7 - R12



Octave Band Frequency (Hz)

Figures 4.15 to 4.18 – Measured and Predicted Octave Band Reverberation Times at Source Position S3

Figure 4.15 - Measured at R1 - R6

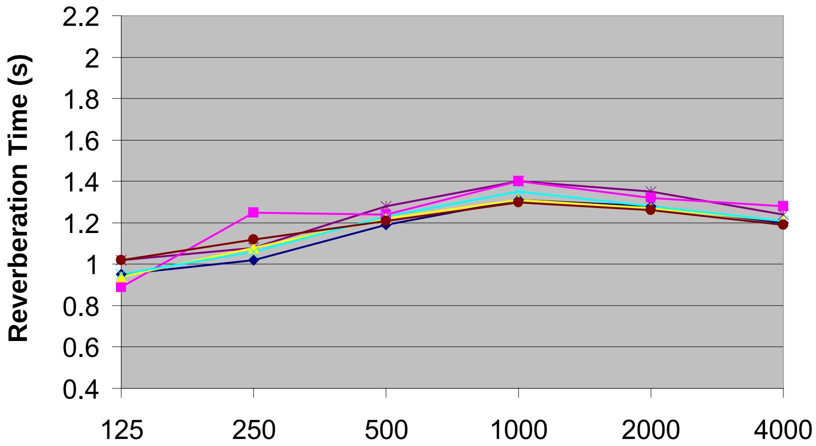
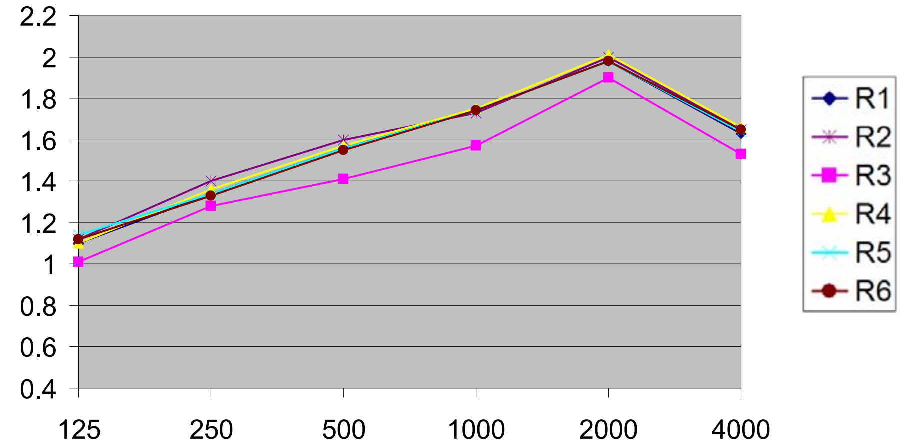


Figure 4.16 - Predicted at R1- R6



Octave Band Frequency (Hz)

Figure 4.17 - Measured at R7 - R12

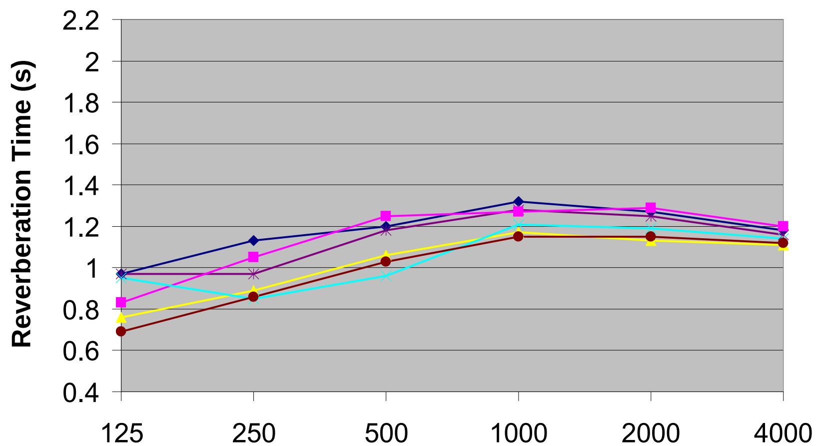
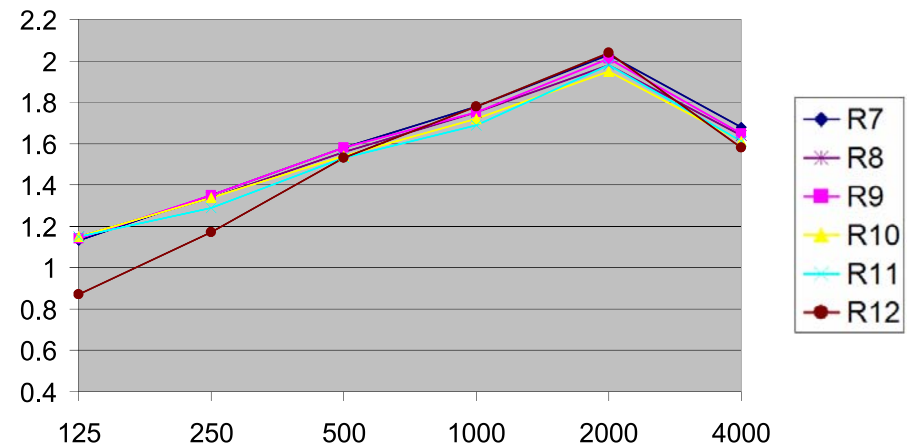


Figure 4.18 –Predicted at R7 - R12



Octave Band Frequency (Hz)

Figures 4.19 to 4.22 – Measured and Predicted Octave Band Reverberation Times at Source Position S4

Figure 4.19 - Measured at R1 - R6

Figure 4.20 - Predicted at R1- R6

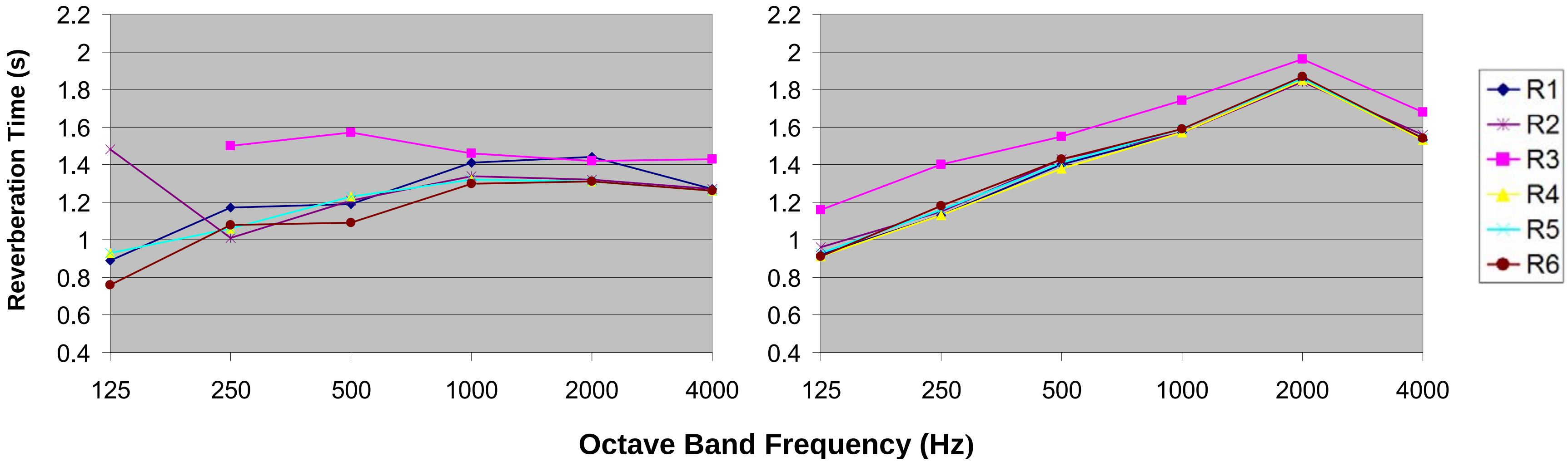


Figure 4.21 - Measured at R7 - R12

Figure 4.22 - Predicted at R7 - R12

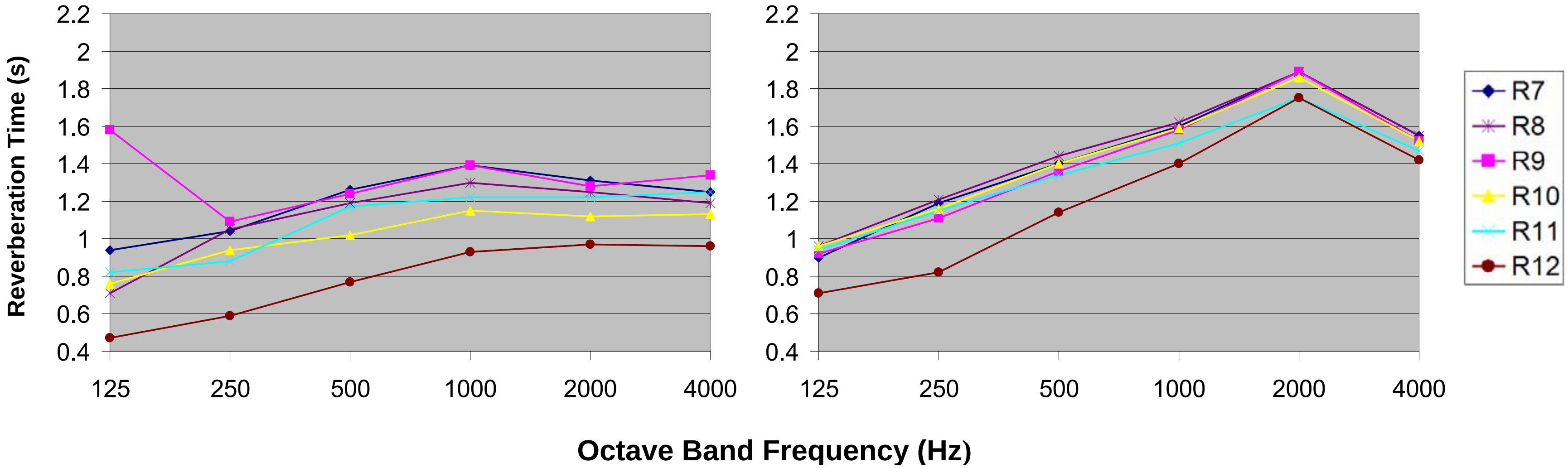


Figure 4.23 – Octave band reverberation times at source and receiver position S1 and R1 predicted using various humidity percentages.

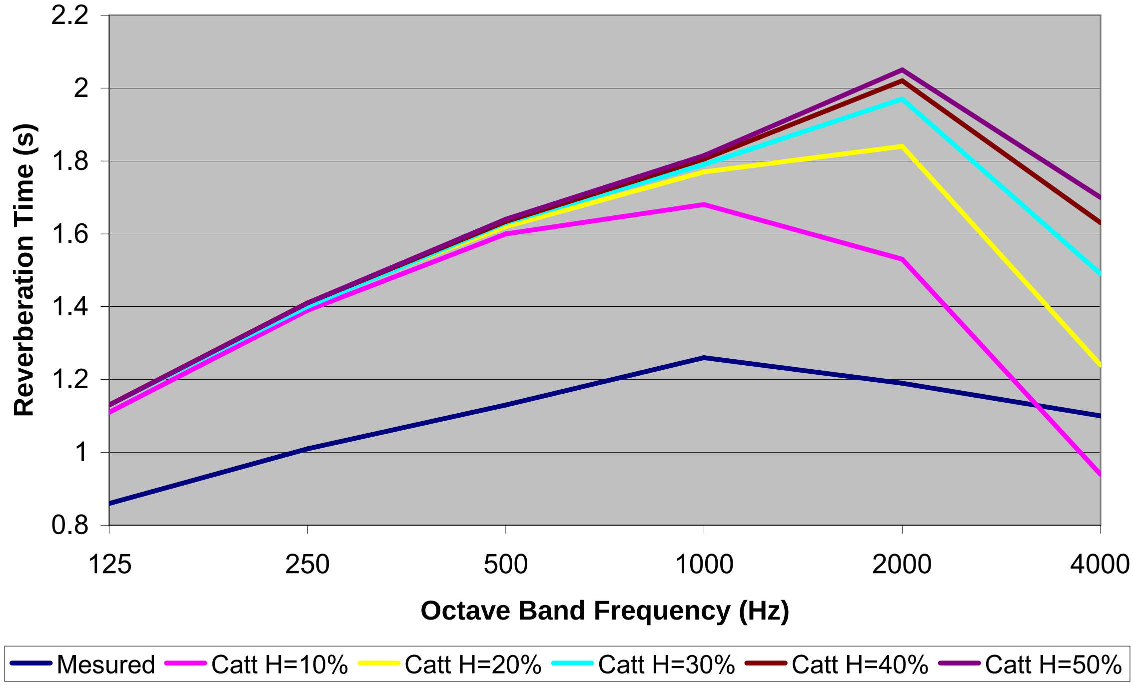


Figure 4.24 – Total and source group average octave band reverberation time prediction error percentages

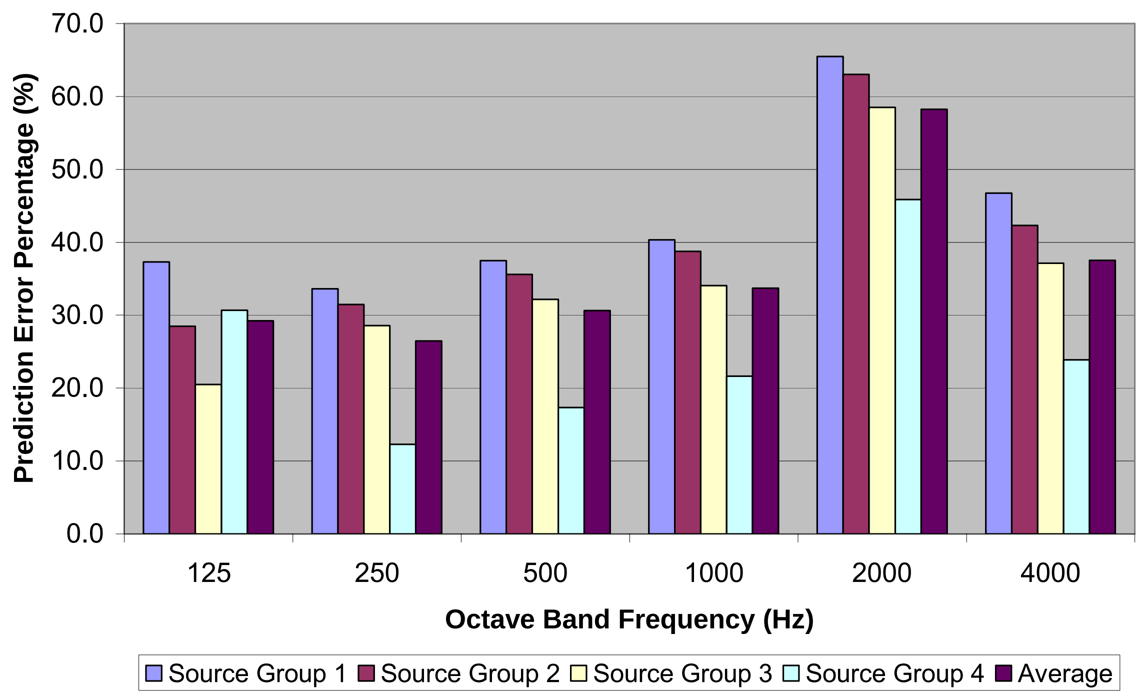
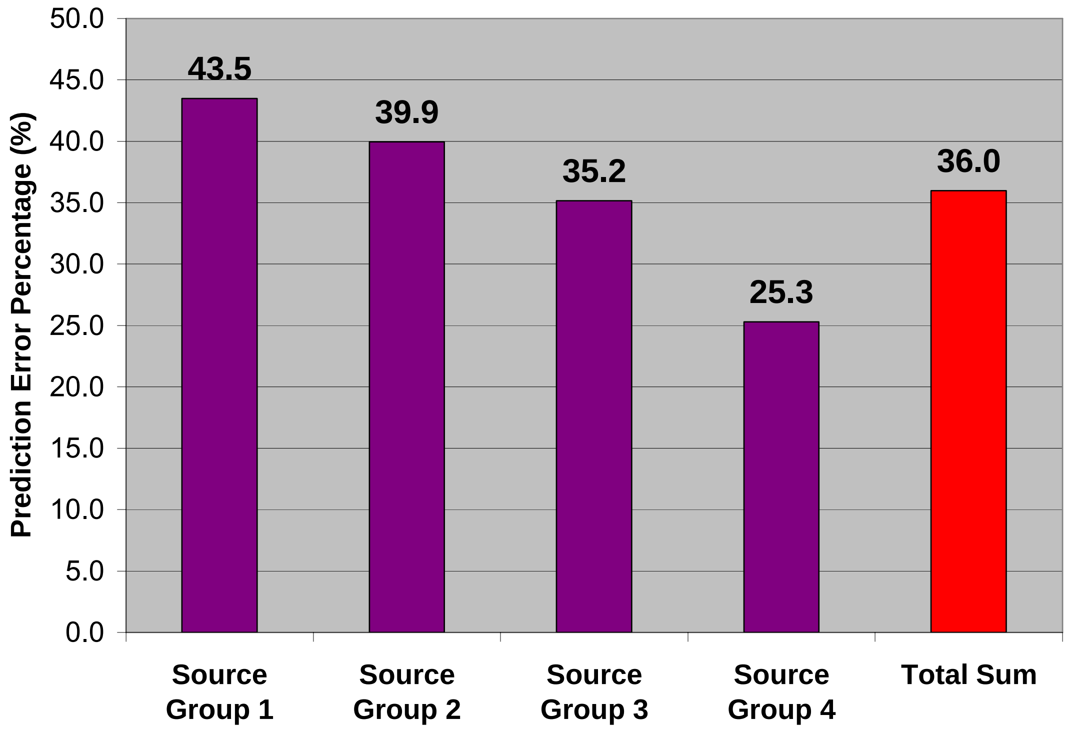


Figure 4.25 – Total sum and source group average reverberation time prediction error percentages



4.6 – Analysis

As mentioned previously, because the RTs are in themselves invalid, this section will only asses the differences between measured and predicted RTs and not ascribe significance to their actual values.

By comparing all of the RTs in each group It is clear that in all source groups and particularly at higher octave bands, the prediction magnitudes have been significantly overvalued. There are also significant differences between there spectral shapes across the octave bands. In virtually all of the measured results the RTs peak at 1KHz whereas in the predicted results, this occurs at 2KHz and is much more prominent. In addition, the rate of change between the 125Hz and peak octave band is much steeper for the predicted results.

Although there are many differences there is one continuity between the sets results in the first source group worth noting *(Figures 4.7 – 4.10)*. All of the measured and predicted RTs from the main room, ladies toilet and middle room, R1 to R10, display comparative levels of deviation within their groups and it is only the values from the men's toilet and back room that deviate from this. However, the measured results show that in these positions there is an increase in the RTs across the octave bands whereas the predictions suggest a decrease. In addition, the measurements suggest that there is a form of bass trap at 500Hz in the back room and more significantly the men's toilet but this is not picked up on by the model.

The differences between both measurements and predictions in souse group two *(Figures 4.11 – 4.14)* are relatively insignificant apart from the absence of the bass trap discussed previously. In source group three *(Figures 4.15 – 4.18)*, apart from in the ladies toilet and back room at the lower frequencies, there is very little deviation between the predicted results for the remaining receivers. This trait is not shared by the measurements and particularly at the lower frequencies, the values from the men's toilet, back and middle room display a comparatively significant difference from those in the main room. In addition, the measurements in this source group suggest that the most significant RTs occur in the ladies' toilet whereas the predictions suggest exactly the opposite.

Of all the measurements source group four *(Figures 4.19 – 4.22)* exhibits the most significant variations between RTs across the bandwidth. However, this trait is again not exhibited by the predictions which apart from values from the back room, men's and ladies toilet exhibit the opposite and are all very similar. The only significant continuity between the values in this source group is found in the receiver positions that exhibit the longest and shortest RTs. For both measurements and predictions the longest RTs occur in the ladies' toilet and the shortest in the back room.

It is clear from these comparisons that the model in its present state is not making accurate predictions but the cause of this is difficult to identify. Although the average octave band error percentages are all extremely high *(Figure 4.24)*, apart from at

125Hz there is a consistency between the percentage error order of significance across the octave bandwidth for all source groups. This consistency suggests that the most significant cause of these errors lie in the models ascribed set of absorption coefficients, i.e. independently of source position, there is a spectral consistency in the lack of absorption.

Particularly in a non-diffuse environment, because of the inverse square law, the surfaces closest to a sound source have the greatest potential for absorption. For this reason, if a model ascribes inaccurate absorption coefficient values to a surface, the surfaces closest to the source will have the potential to be a more significant cause of RT prediction error than surfaces that are far away. This is dependent of the specific absorption characteristics assigned to a surface, but if all surfaces were ascribes the same set of coefficient values, this factor would be true.

By taking this factor into consideration and studying the average source group percentage errors *(Figure 4.25),* it would appear that the surfaces in the main room are the greatest cause of prediction error. This observation is based on the fact that the average prediction error is inversely proportional to the relative significance of the surfaces in the main room to each source position. Unfortunately, because the main room has the greatest surface area with the greatest variation of surface absorption coefficients, it is difficult to more accurately pinpoint a cause of error.

Although the absorption coefficient values were all taken from reliable sources, it is difficult to quantify the level of accuracy attained in the assessment of the surface materials. Having a limited knowledge of building construction and no building or renovation plans, it is difficult to asses the internal structure of a solid wall, floor or ceiling. For this reason, there is a strong possibility that errors of judgment could have been made when assessing the surface materials for compatibility with absorption coefficient databases. In addition to absorption coefficients, the accuracy of the diffusion coefficients ascribes to each surface are also questionable.

Independently of specific surface absorption and diffusion coefficients errors, another possible cause of error could be the humidity setting utilised for the prediction cycles. As mentioned previously, the humidity value is used by the model to calculate the absorption of air. It is clear from RTs predicted with various humidity values *(Figure 4.23),* that this parameter can make a very significant difference to the RTs at the higher octave bands. However, because the humidity was not measured at the time of the experiment, ascribing any cause of error to an inaccurately assigned humidity value would be conjectural.

There are additional acoustic factors that will have effected the measured RTs which can't be modelled using Catt. The application version used for this experiment is not able to model semi-transparent surfaces which is a prominent feature of the partition between the middle and back room. In addition, no provisions are made for flanking paths between connecting rooms or the excitable resonances of various objects or surfaces within the club. Although more subtle, the effects of these factors may also have contributed to the differences between measured and predicted results.

4.7 - Conclusion

The process of building a model of any complexity in Catt is a time consuming and troublesome process. One of the central reasons for this is because if a plane direction is required at any angle other than that of the three axis, vast numbers of trigonometric calculations are requited to attain the necessary corner coordinates.

Humidity can have a significant effect on the absorption of air at higher frequencies. Because of this, the lack of accurate environmental conditions such as this can make a significant difference to the prediction accuracy of a model.

It is quite clear that with a total sum RT prediction percentage error of 36%, in its current form, the model is not suitable for some of the planning applications discussed in the introduction. However, the purpose of this experiment was not to create an accurate model but to asses the accuracy of a model built on reliable geometry and coefficient data.

Because no building or renovation plans were available, although the models geometric accuracy is more than sufficient, the accuracy of the absorption coefficient data is questionable. As such, It is likely that the lack of prediction accuracy is not a reflection of a poor modelling application, but of inaccurate coefficient values.

Although beyond the scope of this experiment, with some adjustments to the absorption coefficient data the model's prediction error percentages could be reduced considerably. The process of assigning different coefficient values is relatively simple and with appropriate adjustments, the model could quickly become a useful planning tool.

Section 5 – CONCLUSIONS & FURTHER INFORMATION

5.1 – General Conclusions

The weekly sound exposure of the two subjects tested exceeds the upper exposure action values of the current and future noise at work Directives. However, because the PA system is the most significant cause of noise exposure and an essential design feature of the club, other than the use of hearing protection, little can be done to reduce the employees exposure to noise. Therefore, to comply with these Directives the employers must ensure that ear protectors with an attenuation of at least 8dBA and 11dBA respectively, are worn by bar staff throughout the week.

Independently of the location within the club the effective frequency response of the PA system is poorly balanced. Although this could be improved significantly by implementing the developed equalisation strategy, because of poor low frequency acoustics, there will always be significant variations in the low frequency response at different positions.

The middle and back rooms exhibit average sound level reductions from the centre of the dance floor of 7.9, and 17.2dB respectively and this may be considered desirable for purposes of communication. However, they achieve this level of reduction at a cost of audible definition and balance due to fact that the entire PA system is localised in the main room.

Building a model with any geometric complexity using Catt is a long winded and troublesome process. Although a high degree of geometric detail was implemented in to the model and reasonable assumptions made about the surface coefficient values, an assessment of its prediction accuracy yielded an average prediction percentage error of 36%. However, the model was not adjusted in any attempt to reduce this percentage, and analyses of the data suggested that significant improvements could be attained by adjusting the surface coefficient data.

5.2 – Further Work

Although at the time of the measurements the club was only open on the ground floor, since that period two additional floors with new bar areas have been opened up to the public. As a consequence there are now three possible working areas that are all likely to exhibit different levels of sound exposure. It would be of interest to measure the sound level in these areas so that the possible benefits of job rotation in terms of noise exposure could be assessed.

In addition to noise exposure, because of the new floors, there are many new avenues of possible investigation. A similar evaluation of the general level and frequency distribution could be carried out on each floor and the effects of sound transmission between floors could be assessed.

Because most of the analysis has been of an empty building, It would be of interest to analyse the acoustic properties of the customers. Although work has been undertaken to calculate the various coefficient values for seated audiences, few experiments has been carried out to try and evaluate the acoustic properties of a moving audience.

If with adjustment to the coefficient data the acoustic model of the club could be significantly improved, various planning simulations could be undertaken. Loudspeakers could be simulated and different strategies of improving the acoustics including both acoustic treatment and loudspeaker distribution could be tested.

As mentioned previously, when measuring the RTs for comparison with the Catt predictions, a series of addition parameters were measured using the WINMLS system such as EDT, D50/D80 and STI. Although beyond the scope of this document, it would be of interest to analyse this data.

5.3 – References

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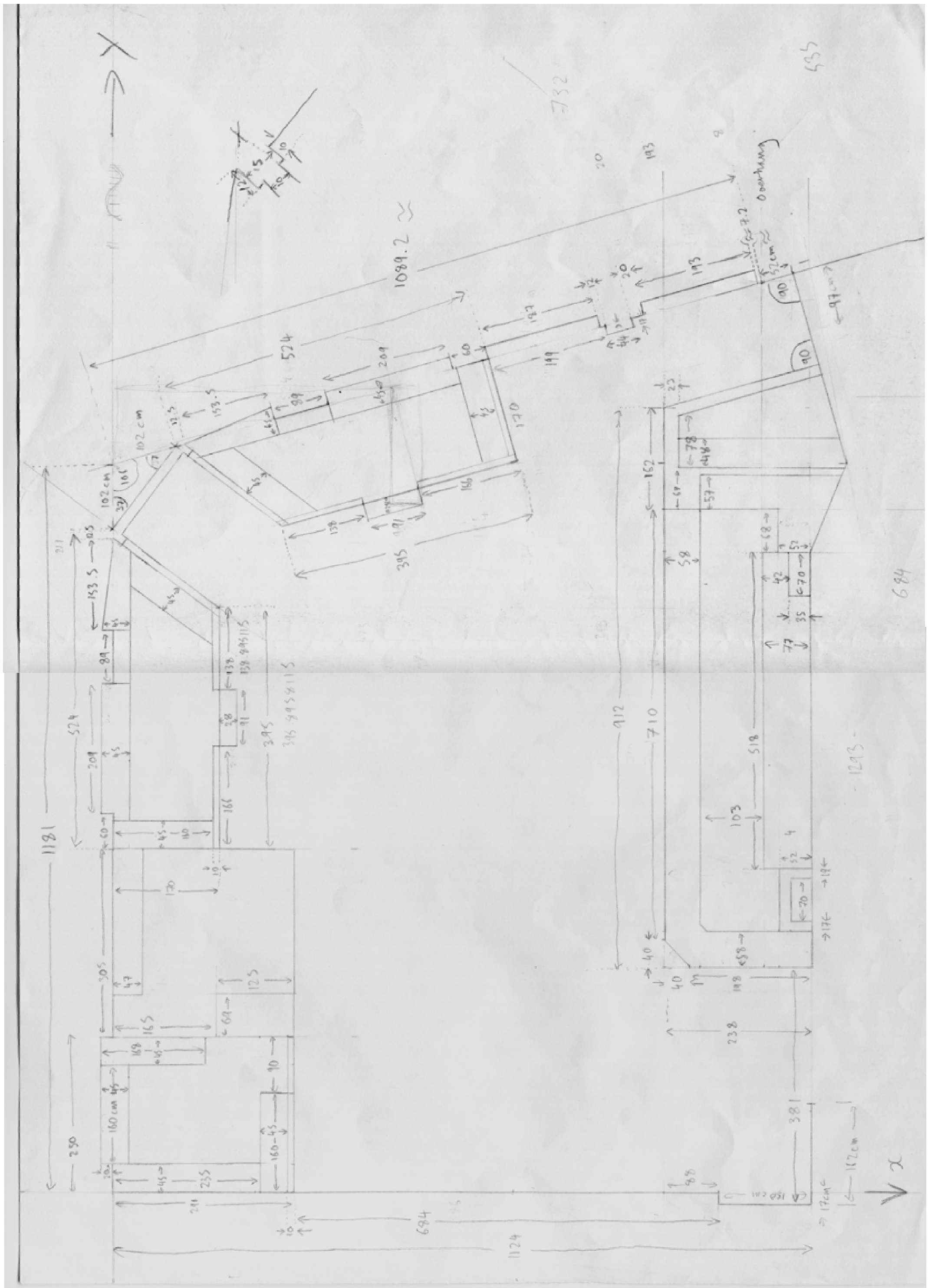
5.4 – Appendices

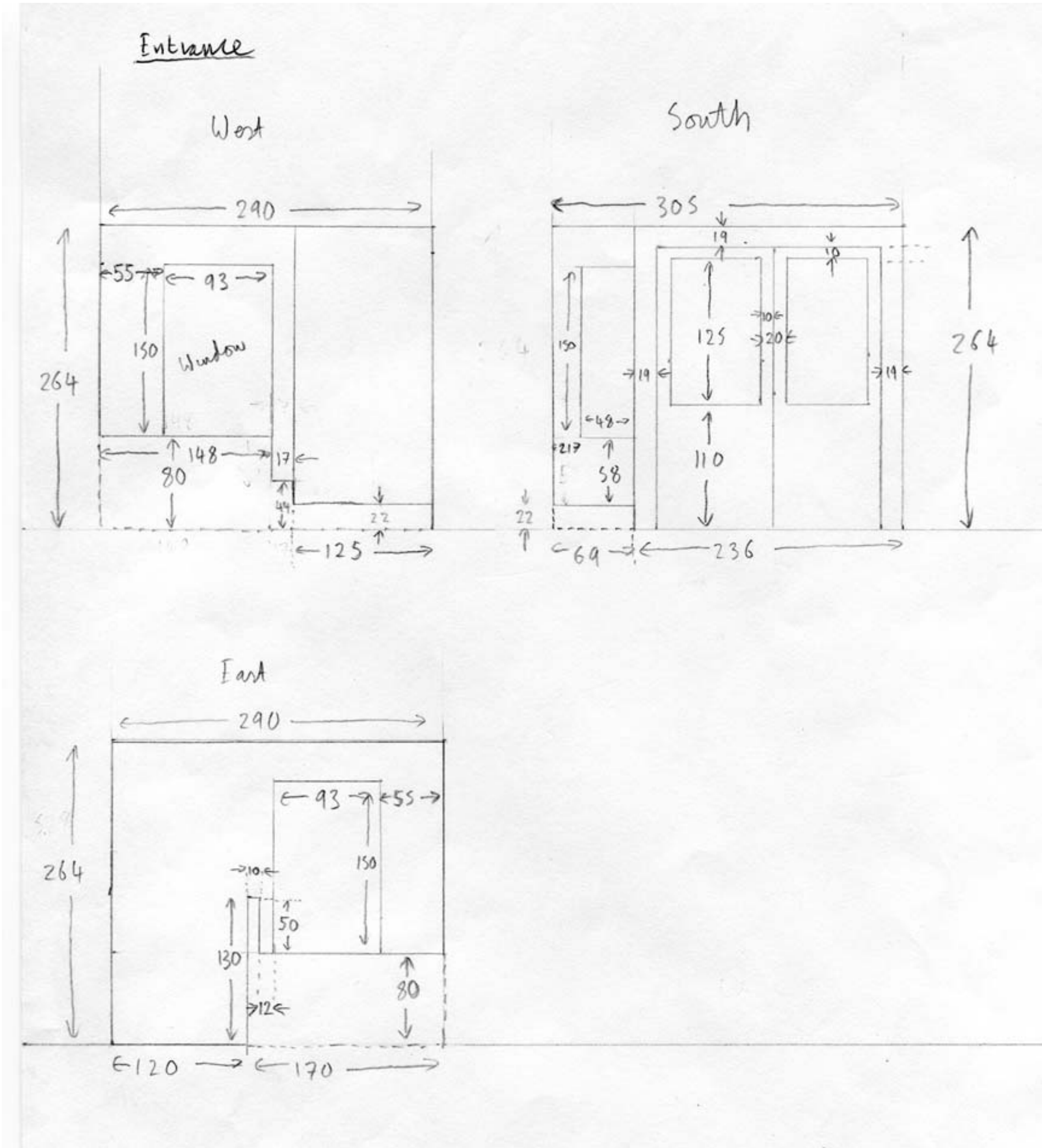
Contents

1. Detailed Sketches of the Dogstar

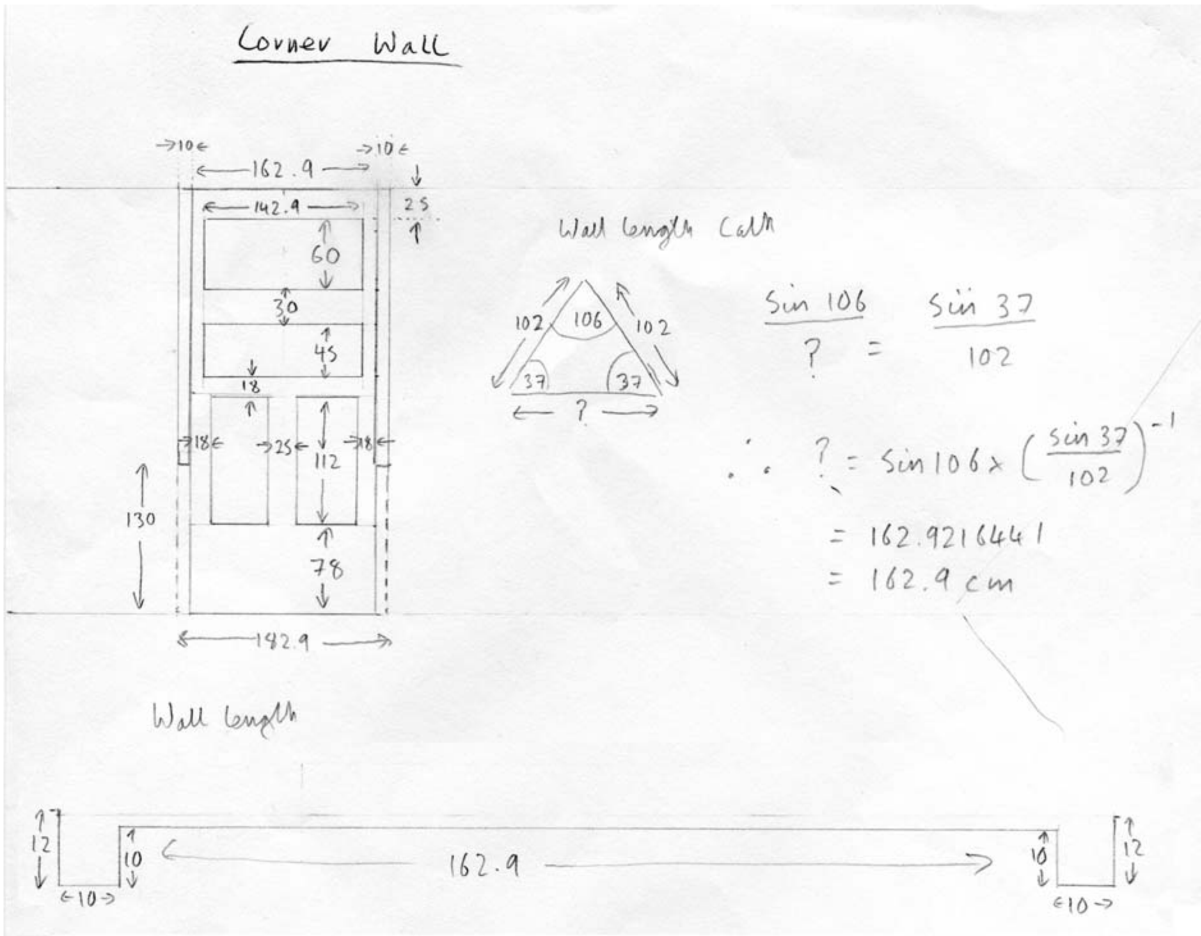
Main Room



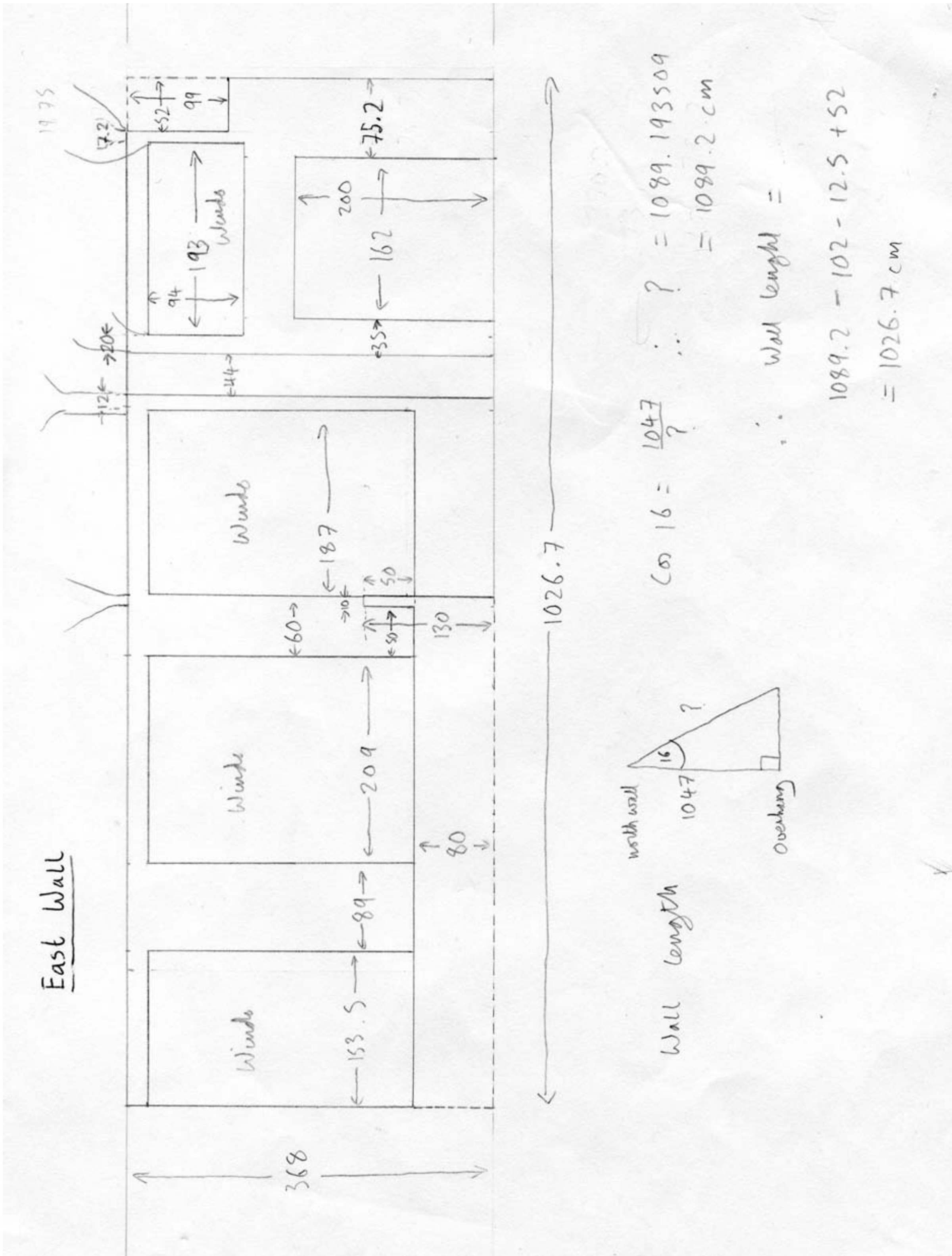
Main Room – Entrance



Main Room – North East Wall

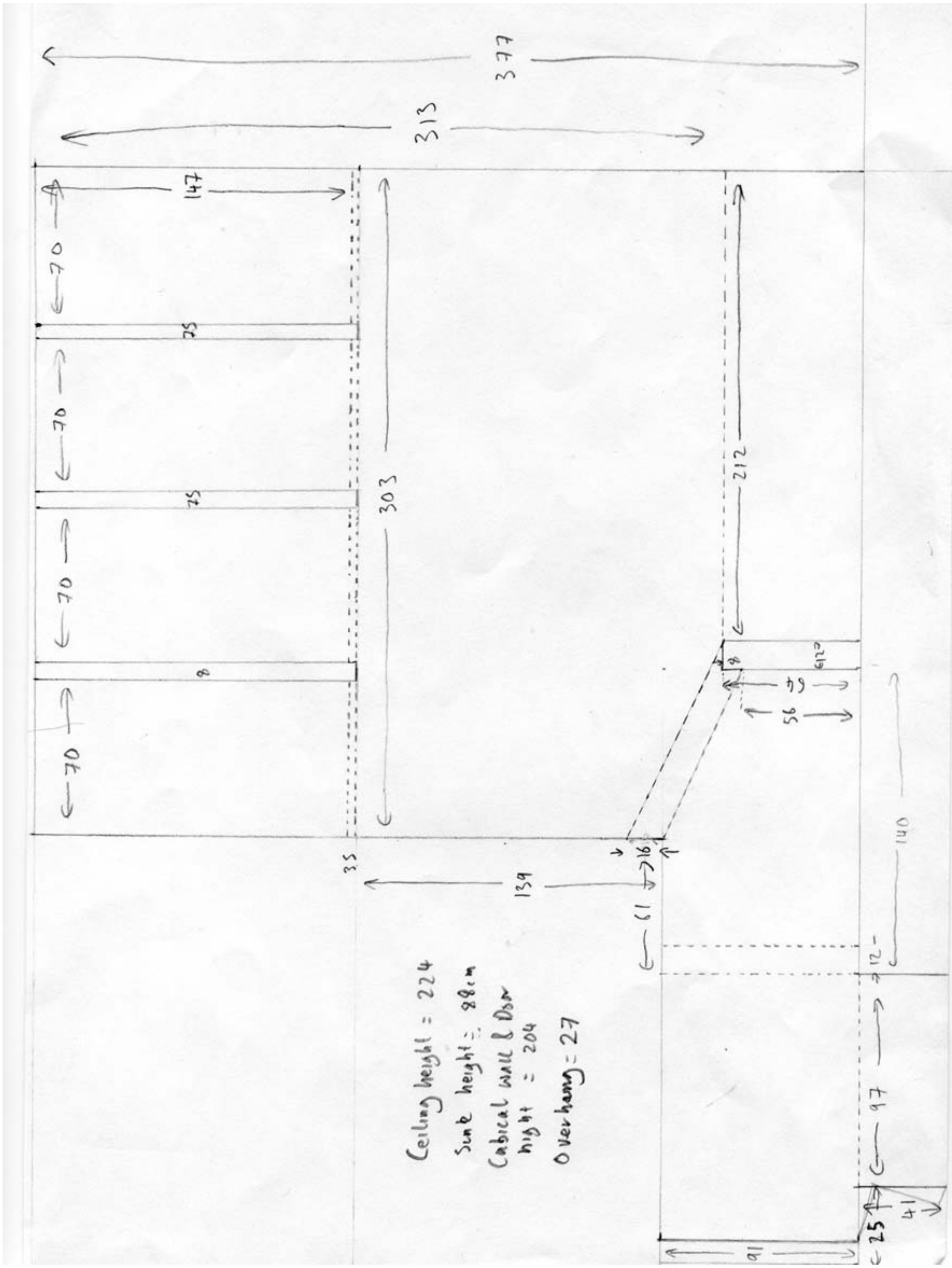


Main Room – East Wall

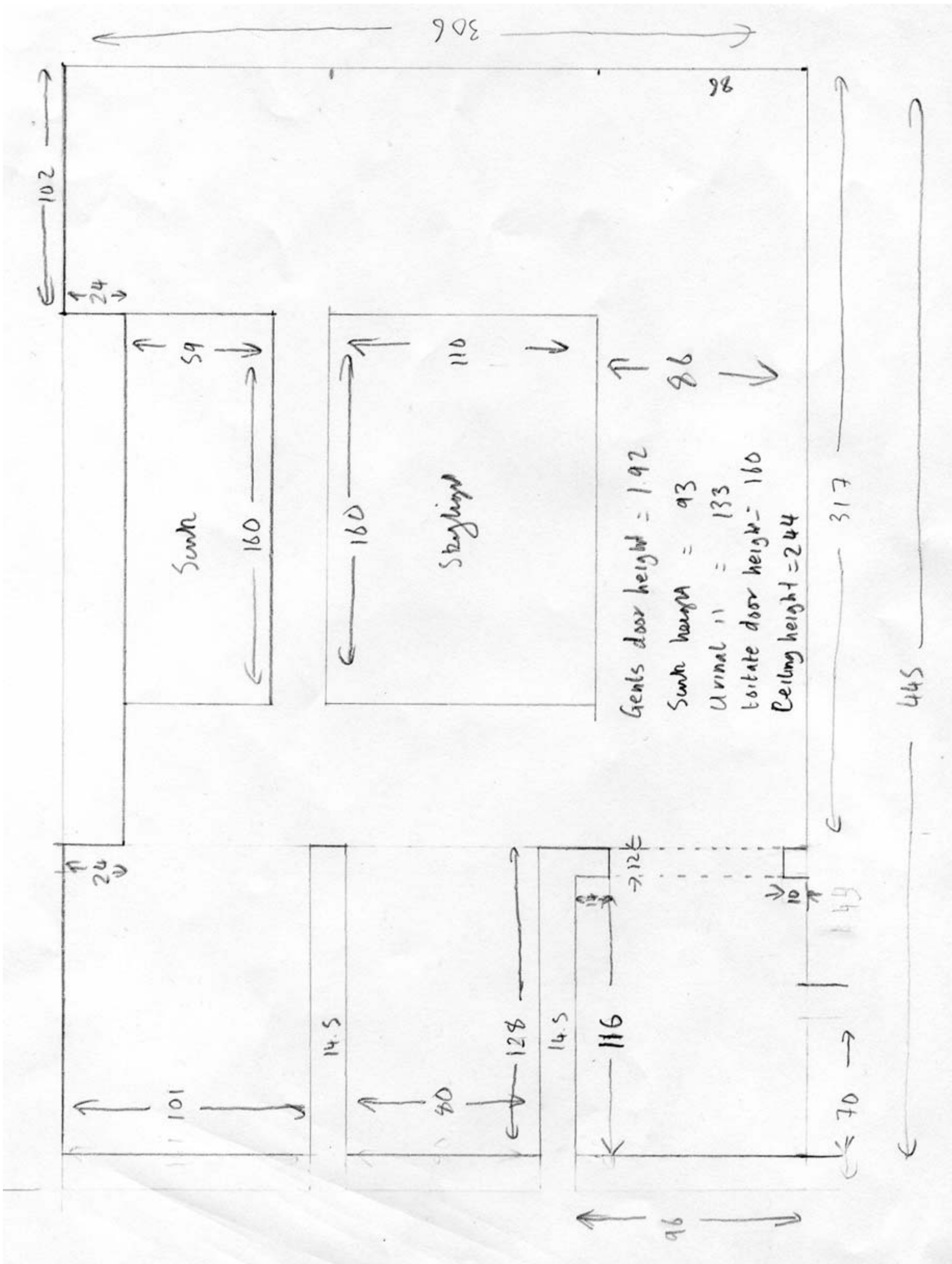


Main Room – South and West Walls

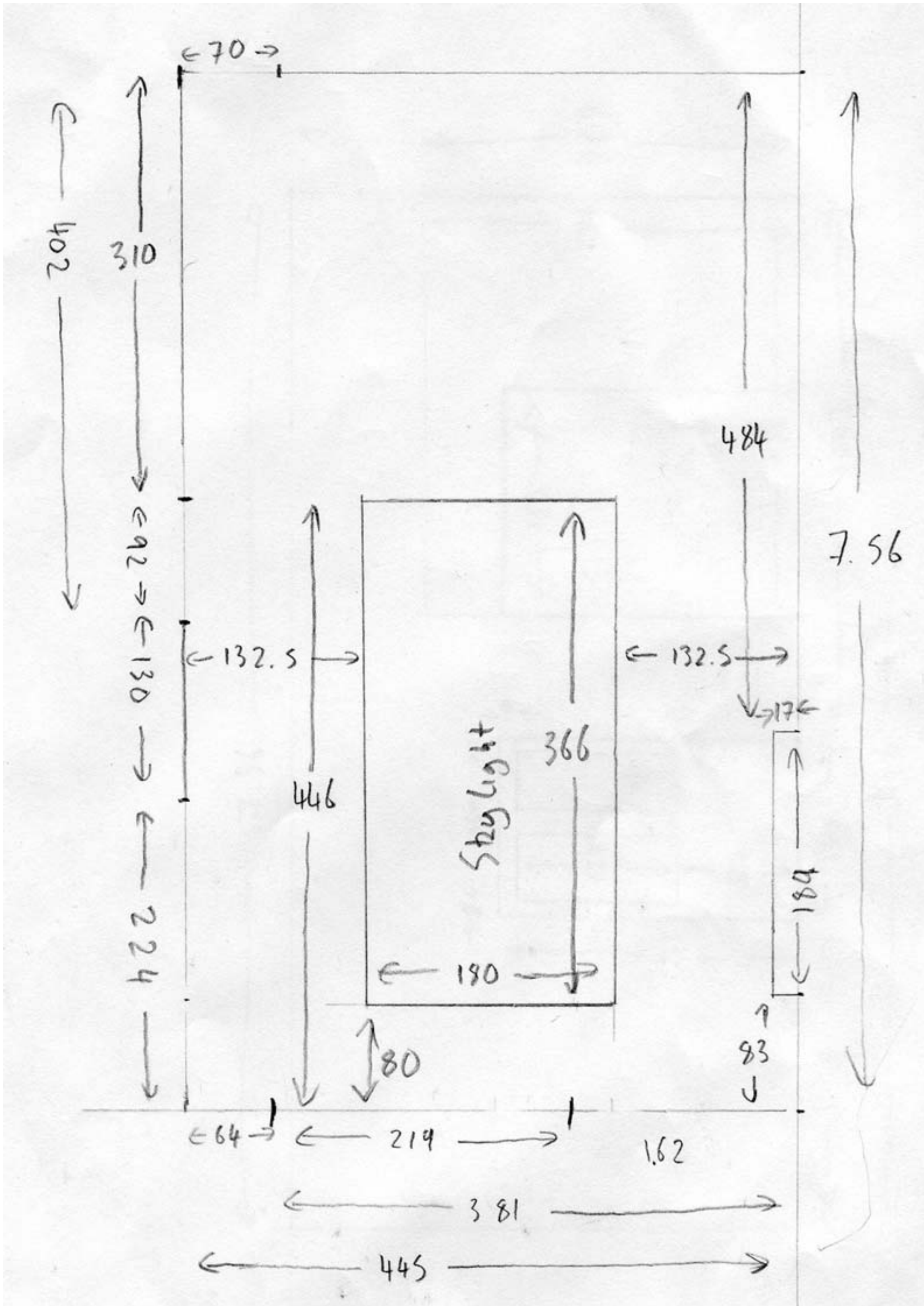
Ladies Toilet



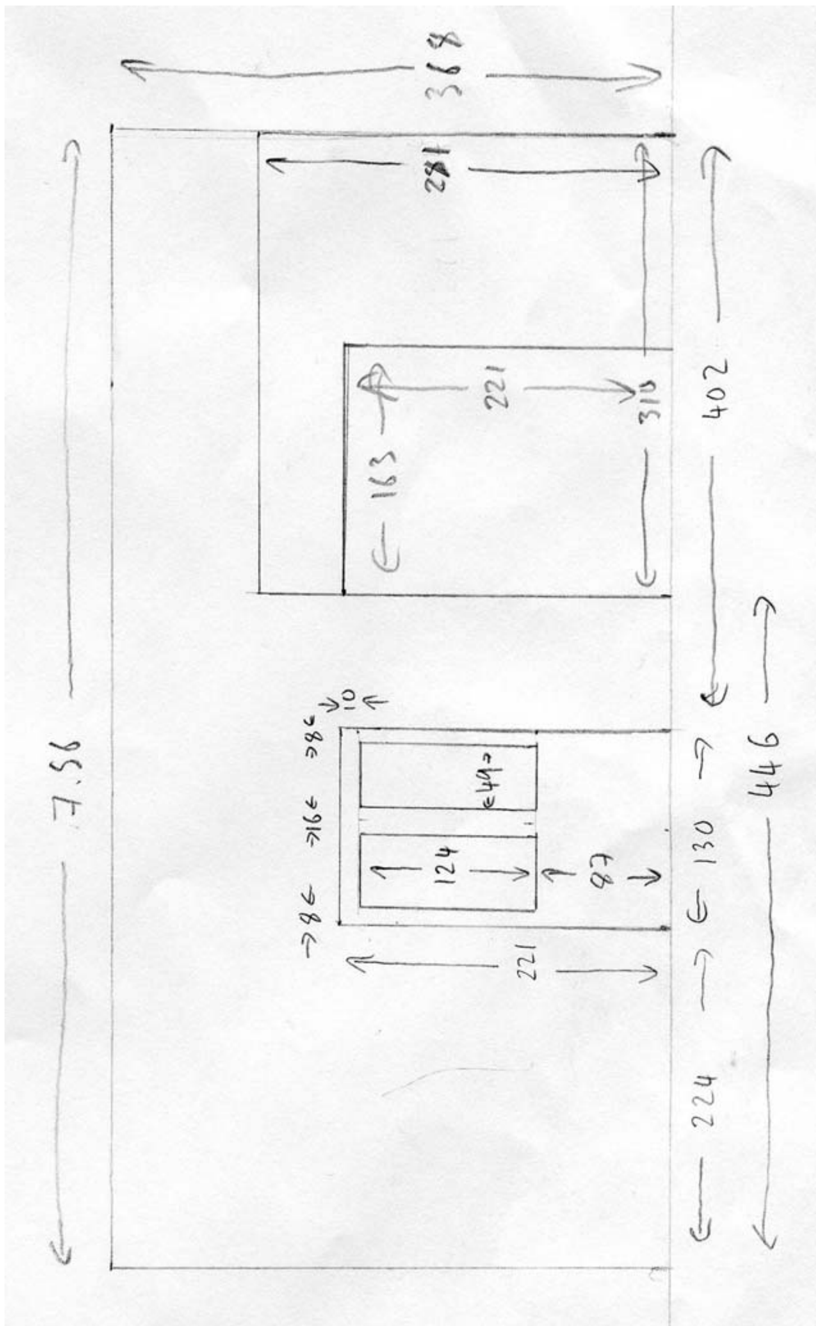
Men's Toilet


306
102
Sink
160
Skylight
110
86
Gents door height = 1.92
Sink height = 93
Urinal " = 133
toilate door height = 160
Ceiling height = 244
317
445
101
80
128
14.5
116
70
96

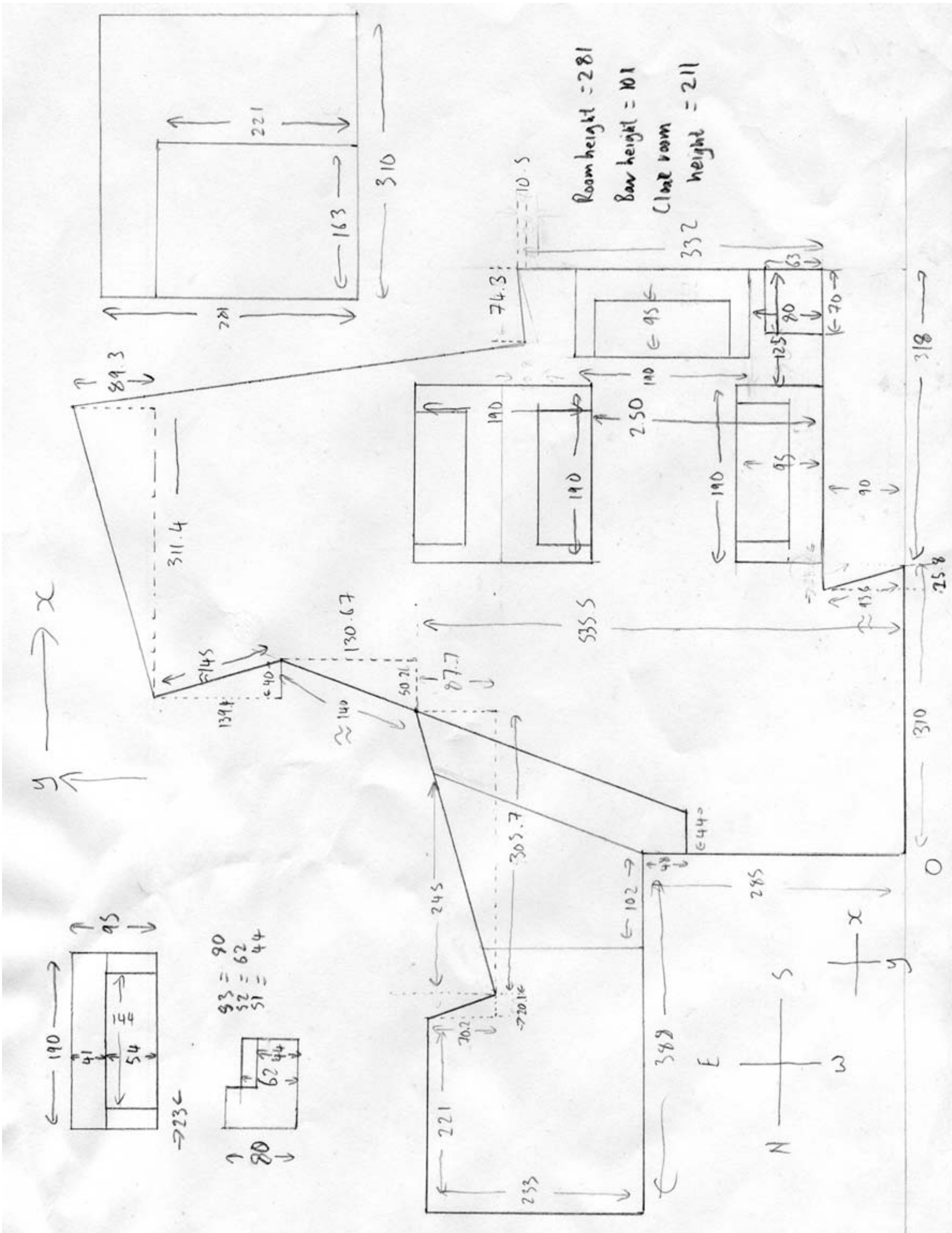
Middle Room


70
402
310
484
7.56
92
130
132.5
132.5
17
366
446
Sky light
184
224
180
80
83
64
219
1.62
3 81
445

Middle Room - East Wall



Back Room



2. Receiver Coordinates for all Broadband L_{Aeq}, Octave and 1/3 Octave band L_{eq} Measurements

Position	X(m)	Y(m)	Z(m)	Position	X(m)	Y(m)	Z(m)
1	*1.3*	*10.79*	*1.7*	**39**	*0.85*	*5.75*	*1.64*
2	*3.7*	*9.41*	*1.7*	**40**	*1.2*	*1.25*	*2.14*
3	*5.7*	*9.41*	*1.7*	**41**	*0.9*	*2.3*	*1.64*
4	*7.7*	*9.41*	*1.7*	**42**	*0.1*	*1.25*	*1.64*
5	*3.7*	*7.41*	*1.7*	**43**	*1.2*	*0.2*	*1.64*
6	*5.7*	*7.41*	*1.7*	**44**	*2.6*	*0.8*	*1.64*
7	*7.7*	*7.41*	*1.7*	**45**	*3.7*	*0.3*	*1.2*
8	*3.7*	*5.41*	*1.7*	**46**	*7.7*	*0.3*	*1.2*
9	*5.7*	*5.41*	*1.7*	**47**	*9*	*0.3*	*1.2*
10	*7.7*	*5.41*	*1.7*	**48**	*10.86*	*0.3*	*1.2*
11	*3.7*	*3.41*	*1.7*	**49**	*11.3*	*14.3*	*1.7*
12	*5.7*	*3.41*	*1.7*	**50**	*13.7*	*12.3*	*1.7*
13	*7.7*	*3.41*	*1.7*	**51**	*15.2*	*11.6*	*1.2*
14	*3.7*	*1.41*	*1.7*	**52**	*14.9*	*12.3*	*1.2*
15	*5.7*	*1.41*	*1.7*	**53**	*14.6*	*12.9*	*1.2*
16	*7.7*	*1.41*	*1.7*	**54**	*14.3*	*13.6*	*1.2*
17	*8.86*	*2.64*	*1.7*	**55**	*12.86*	*2.64*	*1.7*
18	*10.86*	*2.64*	*1.7*	**56**	*14.86*	*2.64*	*1.7*
19	*9.95*	*5.22*	*1.7*	**57**	*16.86*	*2.64*	*1.7*
20	*9.95*	*7.22*	*1.7*	**58**	*12.86*	*0.3*	*1.2*
21	*9.95*	*9.22*	*1.7*	**59**	*14.86*	*0.3*	*1.2*
22	*9.95*	*11.22*	*1.7*	**60**	*16.86*	*0.3*	*1.2*
23	*5.7*	*11.41*	*1.7*	**61**	*18.8*	*0.3*	*1.2*
24	*7.7*	*11.41*	*1.7*	**62**	*18.8*	*2.64*	*1.2*
25	*7.7*	*13.41*	*1.7*	**63**	*19.4*	*4.1*	*1.7*
26	*9.7*	*13.41*	*1.7*	**64**	*20.7*	*1.6*	*1.2*
27	*10.2*	*12.28*	*2.14*	**65**	*22.3*	*3.81*	*1.2*
28	*5.32*	*12.35*	*2.14*	**66**	*21.1*	*3.84*	*1.2*
29	*3.42*	*11.9*	*2.14*	**67**	*18.17*	*5.51*	*1.7*
30	*5.32*	*12.55*	*1.64*	**68**	*18.57*	*7.51*	*1.7*
31	*4.47*	*12.65*	*1.64*	**69**	*18.97*	*9.51*	*1.7*
32	*1.7*	*12.3*	*1.64*	**70**	*19.97*	*11.1*	*1.7*
33	*2*	*11.8*	*1.64*	**71**	*15.7*	*8.3*	*1.7*
34	*0.8*	*6.75*	*2.14*	**72**	*12.82*	*8.3*	*1.7*
35	*0.8*	*8.55*	*2.14*	**73**	*20.6*	*7.8*	*1.2*
36	*0.8*	*10.25*	*1.62*	**74**	*20.6*	*5.7*	*1.2*
37	*0.1*	*10*	*1.64*	**75**	*20.6*	*10*	*1.2*
38	*0.1*	*7.15*	*1.64*	**76**	*22.3*	*7.4*	*1.2*

3. Broadband L_{Aeq} Octave and 1/3 Octave Band L_{eq} Measurements

Broadband L_{Aeq} Measurements

Position	dBA	Position	dBA
1	99.0	**39**	99.2
2	99.9	**40**	99.6
3	99.5	**41**	97.9
4	99.9	**42**	97.7
5	100.6	**43**	98.5
6	98.8	**44**	97.9
7	99.5	**45**	97.6
8	98.9	**46**	97.5
9	98.9	**47**	96.1
10	98.5	**48**	97.2
11	98.6	**49**	95.0
12	98.3	**50**	85.3
13	98.4	**51**	80.3
14	98.5	**52**	81.5
15	97.9	**53**	81.5
16	98.0	**54**	82.1
17	97.5	**55**	93.9
18	96.6	**56**	93.1
19	97.6	**57**	92.5
20	97.3	**58**	93.1
21	97.2	**59**	92.4
22	97.5	**60**	92.2
23	98.9	**61**	92.1
24	99.5	**62**	92.5
25	98.6	**63**	89.8
26	97.3	**64**	83.8
27	97.6	**65**	76.3
28	98.3	**66**	77.0
29	99.7	**67**	84.6
30	98.8	**68**	83.7
31	97.8	**69**	84.2
32	98.1	**70**	83.4
33	98.2	**71**	78.0
34	99.6	**72**	75.7
35	100.1	**73**	83.6
36	98.5	**74**	84.1
37	98.1	**75**	82.1
38	98.7	**76**	82.2

1/3 Octave Band L_{eq} Measurements of the PA System at an output level of 100dBA

Position	20 Hz	25 Hz	32 Hz	40 Hz	50 Hz	63 Hz	80 Hz	100 Hz	125 Hz
1	60.9	70.3	83.4	93.0	93.5	88.2	77.4	86.4	86.1
2	57.5	66.1	76.2	85.7	88.9	81.8	80.1	85.2	91.6
3	54.1	65.2	78.0	88.9	87.8	82.3	85.4	86.9	90.5
4	52.5	61.8	78.9	88.9	84.8	88.0	81.9	83.3	85.6
5	53.7	63.1	70.4	81.9	82.7	83.7	81.2	84.5	89.1
6	53.3	63.3	75.0	80.3	80.1	87.0	77.9	85.7	89.8
7	57.1	62.8	73.6	80.9	83.4	85.1	82.3	83.8	89.1
8	53.2	67.1	74.6	85.8	88.4	81.4	83.2	86.9	86.9
9	56.7	65.5	78.2	88.4	87.3	87.3	81.0	87.6	88.5
10	61.0	62.8	74.3	87.4	86.8	85.0	83.1	80.1	86.3
11	56.2	65.7	78.3	89.6	89.2	88.9	83.9	86.0	86.9
12	58.1	64.8	79.2	89.1	84.9	87.6	84.9	87.5	88.5
13	63.2	60.3	76.7	86.5	88.1	87.1	81.7	88.6	87.6
14	63.6	64.2	80.0	89.2	90.1	87.0	87.1	91.8	89.4
15	61.0	66.6	81.6	89.0	90.3	90.8	90.5	87.8	88.5
16	63.8	64.3	76.0	83.7	91.9	91.3	89.7	90.6	85.8
17	64.0	62.9	79.6	82.3	86.7	90.1	85.1	81.9	87.4
18	62.5	65.1	77.7	84.3	85.2	84.1	86.7	85.0	87.6
19	63.6	65.0	80.9	91.1	86.8	85.0	87.0	79.8	85.6
20	62.7	65.1	72.7	81.9	82.8	85.5	84.3	81.2	79.7
21	61.2	66.0	79.2	90.2	86.3	84.7	84.6	82.1	85.0
22	61.1	68.4	82.4	87.6	87.9	86.6	85.1	84.9	84.9
23	58.9	69.1	75.9	86.2	85.3	84.1	84.9	86.2	91.3
24	56.6	63.3	79.4	84.2	92.9	89.5	87.5	85.3	92.7
25	60.3	66.3	84.0	90.8	94.6	92.7	93.5	95.3	95.4
26	62.3	68.5	75.0	84.6	90.1	89.2	83.8	90.7	86.8
27	61.7	68.8	73.8	84.9	94.2	84.4	83.0	90.0	86.0
28	61.0	70.7	75.7	88.6	87.1	83.7	86.0	85.2	86.9
29	62.1	71.9	82.3	84.5	90.3	79.2	84.0	82.7	91.1
30	60.2	69.8	79.8	88.3	91.9	91.3	92.0	89.9	94.9
31	61.8	72.6	77.3	87.9	90.5	83.8	88.7	89.2	95.0
32	63.2	72.7	85.4	91.4	84.8	89.4	85.6	87.7	89.1
33	62.3	71.7	84.3	90.3	83.4	88.2	85.8	83.9	88.0
34	57.9	63.1	78.3	83.5	87.2	86.0	78.3	80.9	89.9
35	58.6	72.9	86.8	91.7	90.8	89.1	79.0	82.3	87.2
36	60.7	66.9	78.2	91.5	94.1	86.2	83.9	83.2	84.3
37	59.8	66.7	78.6	92.5	95.9	88.8	85.4	88.4	94.4
38	56.9	68.2	85.4	90.1	88.3	84.5	86.1	87.8	91.3

Position	160 Hz	200 Hz	250 Hz	315 Hz	400 Hz	500 Hz	630 Hz	800 Hz	1k Hz
1	91.9	89.3	87.1	90.6	89.4	90.3	89.0	90.6	88.4
2	91.3	89.5	89.3	92.3	92.6	92.5	89.2	91.8	91.0
3	87.8	89.3	91.5	91.1	91.3	89.6	89.4	91.5	90.2
4	88.7	90.6	89.7	93.8	93.1	92.1	92.2	91.7	91.3
5	87.9	88.5	92.9	93.8	92.8	93.6	92.1	92.7	91.1
6	92.2	88.6	88.5	92.4	89.1	87.8	89.6	92.3	88.5
7	91.3	88.3	91.7	92.7	92.1	89.9	90.0	92.6	90.3
8	86.7	86.4	88.6	91.8	89.8	89.1	90.3	91.2	90.3
9	89.0	85.0	89.0	92.7	90.4	90.5	88.2	90.5	89.9
10	88.4	87.6	89.3	91.0	90.5	87.7	89.0	90.7	90.3
11	87.9	90.9	91.7	90.2	89.1	92.3	90.2	88.7	89.1
12	87.4	88.5	87.8	89.4	89.5	89.7	90.2	90.7	89.5
13	89.6	88.2	89.6	91.8	91.7	89.5	89.5	91.5	89.4
14	88.7	87.5	89.0	89.8	89.7	90.1	89.2	91.3	89.1
15	91.1	85.9	88.6	89.6	90.6	88.6	88.7	90.0	88.1
16	88.4	88.2	91.4	90.3	92.3	89.4	88.8	90.0	87.8
17	91.7	85.7	88.3	90.8	89.5	88.2	87.6	89.7	88.1
18	89.2	85.4	86.3	87.6	89.8	88.9	87.8	88.0	87.4
19	92.3	86.2	87.0	89.3	90.9	88.6	88.0	90.4	88.1
20	85.1	85.3	87.5	89.6	89.2	88.6	88.9	89.3	87.8
21	88.0	87.6	85.0	87.0	87.9	87.7	88.3	89.0	87.7
22	91.0	84.3	86.5	88.9	91.1	90.1	88.3	90.1	87.4
23	87.0	90.6	90.4	91.9	90.7	88.9	90.5	92.1	89.9
24	92.4	91.1	89.5	90.2	90.5	90.1	89.7	93.1	90.1
25	91.6	91.2	92.2	90.5	90.7	91.5	89.2	91.7	89.5
26	89.8	86.7	92.3	90.6	89.2	89.3	88.8	90.1	87.7
27	88.4	87.4	89.8	91.8	90.8	90.4	88.4	91.7	87.4
28	90.4	88.6	91.8	92.8	91.6	90.0	90.8	90.7	89.2
29	92.9	90.9	90.1	90.0	92.1	92.2	91.5	92.8	91.4
30	94.8	89.6	89.5	91.9	92.2	92.3	90.2	92.1	89.1
31	89.6	90.5	93.1	97.2	91.9	90.3	90.1	89.6	87.4
32	91.5	91.1	92.4	93.4	93.7	91.3	88.5	91.9	89.0
33	90.0	89.3	89.0	90.8	90.8	92.3	90.1	90.5	89.7
34	93.1	92.3	91.8	90.5	93.4	92.6	91.4	91.5	90.7
35	91.3	89.8	90.3	94.5	92.3	91.7	90.8	91.8	91.2
36	93.2	90.1	89.2	91.7	91.7	92.6	90.8	90.8	89.1
37	94.8	88.2	92.0	93.9	90.2	88.9	87.5	92.8	89.4
38	93.9	92.9	94.1	98.1	93.5	92.0	90.9	87.7	88.9

Position	1k25 Hz	1k6 Hz	2k Hz	2k5 Hz	3k15 Hz	4k Hz	5k Hz	6k3 Hz	8k Hz
1	87.2	87.1	83.9	81.7	81.8	83.1	81.3	79.9	78.2
2	87.4	88.4	86.4	83.3	83.5	85.8	85.4	84.3	82.7
3	89.8	88.1	86.0	84.0	84.0	85.5	84.6	83.4	81.5
4	90.2	88.1	84.8	82.7	83.7	85.5	85.3	83.1	80.4
5	88.7	87.5	85.5	84.0	84.1	85.7	84.1	84.8	83.0
6	87.2	87.1	84.7	84.0	85.1	86.3	84.8	83.7	81.9
7	87.7	88.2	84.6	84.5	83.1	85.7	84.2	83.1	81.2
8	87.9	88.1	85.2	82.9	82.7	84.6	83.6	82.8	82.1
9	88.5	87.2	84.1	82.4	83.6	84.9	83.9	83.1	81.5
10	88.0	86.3	84.5	82.8	83.0	84.1	83.4	82.6	81.3
11	88.1	87.4	84.2	83.5	82.4	83.8	82.7	81.1	79.8
12	88.7	86.6	83.5	82.7	82.8	85.0	83.4	82.4	80.1
13	87.8	86.5	83.8	84.3	82.7	84.0	82.7	81.6	79.8
14	88.0	86.4	84.7	83.3	82.5	84.2	83.9	82.6	81.6
15	87.3	85.9	83.0	82.9	82.6	83.9	82.7	81.3	79.3
16	88.2	86.0	83.0	81.2	82.7	82.8	82.2	80.9	79.1
17	88.9	85.9	83.2	81.6	82.4	83.8	82.9	81.0	79.2
18	85.6	85.5	81.2	82.0	81.6	82.6	80.8	79.9	78.0
19	86.4	85.3	83.0	82.6	82.5	84.3	82.0	80.8	79.0
20	87.9	86.1	83.3	82.9	82.7	84.1	82.5	80.7	79.4
21	87.9	86.3	82.9	81.0	81.2	83.4	81.7	81.1	79.8
22	87.5	86.5	83.0	80.8	81.1	82.9	81.7	80.7	79.2
23	89.2	87.7	84.5	82.5	82.2	84.0	82.6	80.9	79.7
24	90.3	88.3	83.9	83.0	83.6	85.7	83.9	82.2	81.4
25	88.6	87.0	83.6	81.8	82.0	83.6	82.3	80.9	78.8
26	87.3	85.7	82.8	81.4	81.1	82.5	81.2	79.9	78.1
27	88.2	86.3	82.4	80.7	82.1	82.5	81.3	80.4	79.1
28	87.0	86.2	83.3	81.8	81.4	82.6	81.3	80.3	78.0
29	88.3	87.4	84.9	83.2	82.8	84.8	82.9	82.6	80.2
30	88.7	86.6	84.1	81.8	82.0	83.0	81.1	79.8	78.6
31	85.2	84.3	81.1	79.6	80.3	80.6	79.2	78.4	75.9
32	87.4	86.7	82.3	81.2	80.8	82.5	80.5	79.3	77.0
33	88.1	87.1	83.9	82.0	82.0	83.4	81.9	80.4	78.6
34	90.6	88.3	85.1	82.0	82.5	84.0	82.2	81.7	79.5
35	88.3	87.9	84.5	83.0	83.2	83.7	82.3	81.5	79.7
36	88.7	86.6	83.4	81.3	81.9	83.1	81.4	80.2	78.2
37	87.9	87.8	82.9	81.4	81.7	82.4	80.5	79.1	77.4
38	87.9	87.0	83.6	82.8	82.2	83.6	81.4	80.4	78.5

Position	10k Hz	12k5 Hz	16k Hz	20k Hz
1	75.1	70.3	65.5	58.9
2	81.3	78.0	75.4	70.3
3	80.4	77.5	75.1	69.6
4	79.6	75.5	73.2	67.7
5	81.8	78.8	75.9	70.2
6	79.3	78.1	74.7	68.9
7	80.7	76.5	74.9	67.8
8	79.6	76.1	72.7	66.8
9	80.2	75.8	73.1	66.9
10	79.4	75.7	72.2	66.0
11	78.0	74.0	69.6	62.8
12	78.8	74.6	70.9	65.0
13	77.1	73.2	70.1	64.2
14	79.4	76.6	73.7	67.0
15	77.5	73.3	70.0	62.9
16	76.5	72.1	68.9	61.6
17	76.7	72.4	69.2	62.8
18	75.9	72.0	67.9	60.6
19	77.2	73.4	70.0	63.0
20	77.4	74.6	71.6	64.5
21	76.9	73.2	69.0	63.3
22	77.2	73.1	69.3	62.2
23	77.7	74.3	69.0	64.0
24	79.1	76.4	73.5	67.4
25	76.6	71.6	66.3	59.6
26	75.7	71.2	66.7	60.5
27	76.3	71.4	67.2	61.9
28	75.0	70.9	66.8	60.8
29	77.8	73.0	68.4	64.9
30	75.3	70.9	66.9	61.1
31	73.1	68.5	63.1	57.4
32	74.5	69.4	64.0	58.1
33	76.6	72.0	67.4	62.0
34	77.3	73.6	69.2	64.8
35	77.8	74.6	70.6	65.4
36	75.4	70.9	65.8	59.8
37	74.2	69.1	64.0	57.1
38	75.3	70.8	65.8	59.2

Position	20 Hz	25 Hz	32 Hz	40 Hz	50 Hz	63 Hz	80 Hz	100 Hz	125 Hz
39	60.8	72.1	86.7	92.7	91.6	90.4	86.5	87.7	93.7
40	69.8	67.5	78.6	85.6	85.4	79.3	76.2	82.1	87.4
41	69.8	69.9	80.1	87.6	90.4	86.4	86.8	89.0	90.0
42	70.5	70.5	81.9	89.4	90.8	89.8	85.1	83.6	91.1
43	70.4	69.3	77.3	83.8	80.1	86.9	90.2	90.8	91.4
44	66.8	66.3	70.0	83.6	88.5	89.8	86.2	89.3	90.7
45	64.4	67.6	81.7	91.6	93.4	96.7	92.4	91.9	88.7
46	64.6	66.3	77.3	87.5	95.8	94.8	95.5	93.4	92.3
47	66.0	67.2	82.6	85.6	90.7	91.1	95.8	93.5	88.6
48	66.3	68.3	82.2	89.8	94.2	93.9	94.5	90.8	90.3
49	68.1	71.2	77.2	93.7	94.3	88.1	90.6	83.9	77.4
50	55.5	61.4	65.4	80.4	79.6	86.7	81.5	70.1	68.2
51	57.1	66.4	80.6	93.0	84.0	80.8	77.9	73.1	64.0
52	56.5	65.2	73.8	84.0	86.2	79.2	74.0	69.1	61.6
53	58.4	62.9	74.5	94.8	95.2	78.7	75.5	69.6	73.2
54	55.0	61.6	76.9	88.4	88.5	81.1	81.4	75.1	66.5
55	55.7	66.2	77.6	78.9	84.4	79.3	81.5	79.6	83.7
56	54.5	59.1	77.9	82.0	87.8	82.5	78.8	76.5	85.5
57	61.9	65.5	70.1	76.4	83.7	78.7	80.8	79.3	84.3
58	55.3	67.2	81.1	85.5	91.3	84.1	86.2	82.4	83.0
59	56.5	58.3	79.0	84.3	93.9	91.0	85.5	81.9	81.8
60	63.0	64.0	78.5	81.4	89.3	80.8	82.2	81.9	88.3
61	64.4	68.0	81.3	85.8	92.9	92.0	88.3	84.3	87.6
62	63.5	66.7	79.3	81.5	89.8	85.1	85.0	83.9	82.6
63	59.0	64.8	81.5	82.2	92.0	86.4	82.5	71.2	67.6
64	51.5	51.4	64.0	68.9	74.6	68.6	70.4	65.7	68.5
65	59.2	63.1	63.8	76.4	78.7	68.6	67.4	65.7	68.2
66	54.1	57.3	66.6	83.1	86.1	76.9	67.6	61.8	63.3
67	52.7	59.4	65.8	73.4	81.6	74.1	77.4	68.7	73.3
68	51.4	50.5	62.3	70.8	79.5	72.8	76.6	70.6	71.4
69	54.8	62.1	55.5	64.2	74.8	69.0	72.2	68.9	67.4
70	60.9	64.7	57.2	66.0	69.1	71.3	69.5	68.4	71.3
71	61.2	55.3	58.7	71.3	77.3	64.7	66.5	67.1	68.6
72	59.0	57.0	67.4	68.0	67.1	57.4	61.9	61.6	58.3
73	55.7	62.4	60.2	71.0	82.1	72.8	71.3	67.2	67.6
74	49.3	54.0	63.7	72.9	81.4	70.2	71.4	69.1	70.1
75	54.4	63.1	64.6	70.1	81.7	72.3	71.2	71.0	69.3
76	58.7	66.9	69.3	67.4	77.1	72.0	67.4	67.9	68.5

Position	160 Hz	200 Hz	250 Hz	315 Hz	400 Hz	500 Hz	630 Hz	800 Hz	1k Hz
39	94.3	90.6	95.0	90.8	89.8	89.6	92.5	93.4	89.8
40	85.3	88.2	90.9	94.2	92.4	91.7	91.3	93.1	90.4
41	92.1	84.2	87.4	89.3	88.0	89.7	90.9	91.3	88.4
42	93.1	90.3	90.3	91.2	90.4	91.8	90.4	90.5	87.6
43	92.1	89.8	92.7	90.4	88.0	90.8	91.2	93.1	89.2
44	89.2	86.8	91.2	92.7	90.6	91.0	89.2	90.0	89.4
45	87.9	84.4	88.1	91.1	91.1	90.1	88.4	90.4	87.9
46	89.4	85.1	88.0	86.4	89.1	88.5	88.9	89.6	89.0
47	90.7	86.2	89.0	89.5	90.3	88.7	88.0	88.7	87.8
48	87.1	83.9	85.3	88.5	87.8	90.5	88.9	89.4	89.5
49	81.2	78.4	81.5	85.6	87.2	86.9	85.5	87.1	83.9
50	73.4	66.6	75.1	76.5	79.8	76.9	76.2	78.9	76.9
51	71.6	60.3	71.3	75.6	75.4	72.6	72.8	71.4	69.9
52	67.4	62.1	73.5	74.0	78.3	75.2	72.4	75.1	70.5
53	73.8	65.7	71.7	75.5	75.5	75.8	74.2	74.2	72.0
54	75.2	63.6	73.4	80.1	78.2	75.5	70.7	74.1	70.8
55	84.1	84.1	84.9	85.1	86.2	86.7	85.3	85.4	84.5
56	81.2	84.9	84.8	85.6	85.7	85.4	84.5	86.0	83.9
57	82.1	80.1	83.3	84.0	84.6	84.7	84.1	85.3	83.7
58	82.1	80.6	82.0	84.0	87.8	86.0	84.3	85.6	84.3
59	78.8	84.7	83.5	82.6	84.8	84.2	84.7	84.8	83.6
60	83.3	85.4	83.2	82.5	83.4	83.5	84.5	84.6	82.7
61	82.7	82.8	81.1	83.6	85.3	84.0	81.7	85.7	83.7
62	81.4	80.6	83.0	86.4	84.7	84.7	83.0	84.9	83.3
63	78.6	76.9	77.7	80.7	80.3	80.9	79.4	82.7	80.4
64	67.5	71.8	75.4	73.9	73.5	75.0	75.6	77.3	75.0
65	64.9	64.9	65.6	68.1	68.4	68.8	68.6	69.0	66.9
66	67.4	59.1	68.0	73.7	72.8	68.2	68.3	70.3	67.3
67	74.5	73.5	74.2	75.3	76.8	76.2	76.1	77.0	75.1
68	70.3	68.0	70.3	77.7	76.0	76.0	75.1	76.9	74.9
69	69.6	73.7	71.9	73.9	73.1	75.9	74.1	76.4	75.6
70	72.8	74.3	72.9	73.1	74.4	74.8	74.3	76.8	75.4
71	66.0	65.9	68.8	72.6	71.3	70.9	69.6	71.1	69.1
72	63.0	66.4	64.3	67.6	67.1	67.0	66.5	69.8	66.8
73	69.0	72.4	72.6	75.4	75.6	75.2	74.6	76.2	74.5
74	69.8	67.8	72.9	77.2	74.0	75.3	75.5	76.2	75.8
75	68.2	70.2	70.2	72.0	74.5	73.7	73.1	75.0	73.1
76	65.6	65.3	69.5	74.7	74.1	72.3	72.3	74.4	73.3

Position	1k25 Hz	1k6 Hz	2k Hz	2k5 Hz	3k15 Hz	4k Hz	5k Hz	6k3 Hz	8k Hz
39	88.4	86.7	84.5	82.6	82.3	83.7	82.2	81.4	79.6
40	89.6	87.9	84.3	82.5	82.5	84.7	83.9	82.2	80.5
41	87.9	87.0	83.3	80.8	80.9	83.3	82.0	80.4	78.5
42	86.1	85.4	82.2	81.1	81.2	82.3	81.2	79.3	77.4
43	89.0	85.9	82.6	82.2	81.3	83.1	82.2	80.8	78.1
44	88.2	86.4	83.0	81.5	81.2	83.0	81.8	80.3	78.6
45	85.8	86.5	83.1	81.6	81.5	83.5	81.9	80.3	79.3
46	88.3	85.4	82.8	80.8	81.8	82.3	82.3	80.2	78.6
47	86.3	85.5	82.2	80.5	81.2	82.3	81.0	79.1	78.6
48	87.1	86.2	82.7	82.2	82.9	82.3	81.5	80.6	78.2
49	82.5	82.2	78.7	77.8	78.7	79.5	78.1	77.0	75.2
50	75.2	74.0	70.3	69.6	69.3	70.4	68.5	66.8	64.2
51	68.5	68.4	63.7	63.7	63.5	64.6	62.9	61.0	58.4
52	69.1	69.0	65.6	63.5	64.1	65.5	63.6	62.1	59.7
53	70.4	69.2	65.4	64.8	64.4	65.3	63.9	62.4	60.9
54	69.4	68.2	64.6	62.4	63.4	64.3	62.5	60.7	58.6
55	83.5	83.2	80.1	78.4	79.7	79.5	78.6	77.3	75.6
56	82.7	81.5	79.6	78.3	78.6	79.4	78.1	76.5	73.8
57	82.4	82.0	78.7	77.0	77.1	79.0	76.9	75.2	72.6
58	82.8	81.5	79.3	78.2	78.9	79.3	77.6	75.7	73.5
59	83.3	81.8	78.1	77.0	77.1	78.1	76.4	74.6	72.1
60	82.5	82.2	78.2	76.4	76.7	77.8	75.9	74.2	71.3
61	82.3	81.6	77.9	77.0	76.5	78.4	75.7	74.2	71.2
62	82.4	81.2	78.5	77.9	76.9	78.5	76.7	75.0	72.2
63	78.7	78.5	76.3	74.5	76.1	76.5	74.7	72.5	70.7
64	73.1	72.7	69.2	68.1	68.3	69.4	66.9	64.7	61.9
65	65.7	65.7	61.5	59.8	60.3	61.0	58.7	56.1	51.9
66	66.2	66.1	62.9	61.4	61.3	61.7	59.3	56.7	52.6
67	73.7	73.2	69.6	69.2	69.0	70.6	68.4	65.8	62.1
68	74.4	73.2	70.1	69.7	69.8	70.6	68.3	66.1	63.0
69	73.9	73.3	70.4	69.5	69.6	70.8	68.4	66.3	62.9
70	74.1	73.0	69.8	69.3	69.2	69.5	67.9	65.2	62.0
71	68.2	67.5	63.8	62.8	62.8	63.5	61.2	58.6	54.4
72	66.3	64.0	61.6	60.2	60.6	61.5	58.7	55.7	51.9
73	73.1	72.9	69.7	68.8	69.1	69.9	67.8	65.4	62.1
74	74.3	74.0	69.7	68.7	69.3	70.5	68.5	66.5	63.4
75	72.0	71.7	67.5	67.6	67.7	69.0	66.3	63.8	60.4
76	72.4	71.4	68.4	67.3	68.3	68.9	66.5	63.9	60.6

Position	10k Hz	12k5 Hz	16k Hz	20k Hz
39	77.4	73.5	68.7	62.3
40	80.0	77.6	75.1	67.9
41	76.9	73.5	68.6	62.3
42	74.6	70.0	65.7	58.9
43	75.8	71.5	66.9	59.7
44	76.2	71.6	66.6	59.2
45	76.4	72.0	67.9	59.6
46	75.8	71.8	67.3	60.7
47	76.3	71.2	68.6	62.0
48	74.9	71.6	68.0	60.5
49	74.0	70.2	67.7	66.2
50	60.5	54.6	47.9	38.7
51	54.5	49.0	41.4	32.9
52	56.6	50.3	43.5	34.4
53	59.4	55.8	53.4	53.0
54	54.7	49.2	42.1	32.8
55	73.4	68.7	64.5	57.6
56	71.1	66.1	61.4	53.7
57	69.5	63.9	59.3	51.5
58	71.8	65.6	63.0	55.4
59	68.9	63.1	58.2	50.5
60	67.4	61.5	55.3	46.0
61	67.3	61.4	55.4	46.3
62	68.8	64.2	58.0	49.5
63	66.9	61.8	55.9	46.4
64	57.3	50.4	43.3	33.1
65	47.1	39.6	31.6	0.0
66	47.7	40.2	32.0	0.0
67	57.5	50.2	43.0	32.2
68	58.6	51.4	45.1	34.9
69	59.0	52.5	46.0	37.2
70	57.8	50.5	43.6	33.7
71	48.9	41.0	32.8	0.0
72	46.6	38.5	30.1	0.0
73	56.9	49.9	43.1	32.7
74	59.1	52.7	46.0	38.9
75	55.6	48.0	41.2	31.1
76	55.9	48.7	41.9	32.3

1/3 Octave Band L_{eq} Measurements of the PA System at an output level of 80dBA

Position	20 Hz	25 Hz	32 Hz	40 Hz	50 Hz	63 Hz	80 Hz	100 Hz	125 Hz
2	58.5	66.8	59.9	69.5	72.0	66.4	63.6	66.8	72.0
3	53.5	65.1	61.4	72.1	69.6	63.2	66.5	68.3	70.2
4	49.7	53.2	60.9	69.7	68.1	68.9	63.4	67.4	66.4
5	52.9	60.7	54.6	65.4	67.9	63.0	61.8	67.3	69.5
6	51.3	60.8	58.9	63.0	63.8	67.7	59.7	67.1	70.7
7	54.1	57.6	56.0	62.8	66.1	64.9	62.3	65.9	69.6
8	55.0	65.3	57.7	68.0	69.9	62.3	63.9	68.1	66.7
9	56.2	63.6	65.4	72.3	70.3	69.0	62.5	70.6	69.8
10	58.5	54.0	57.9	70.4	68.4	66.1	63.7	62.0	66.8
11	57.2	63.7	58.4	70.9	70.9	69.9	65.0	68.6	67.7
12	56.9	59.6	61.6	70.5	66.6	68.1	66.1	69.3	68.6
13	60.6	53.0	59.3	69.4	68.2	67.5	62.3	70.0	68.3
23	58.9	68.0	59.7	67.0	67.5	65.0	65.0	67.6	72.3
24	55.6	60.8	62.9	66.6	73.7	70.0	67.9	66.6	73.2

Position	160 Hz	200 Hz	250 Hz	315 Hz	400 Hz	500 Hz	630 Hz	800 Hz	1k Hz
2	71.8	69.8	70.0	73.4	73.4	72.9	69.2	73.0	72.1
3	66.9	70.5	70.6	70.7	70.7	70.8	73.1	72.0	71.8
4	69.6	71.2	69.7	73.9	72.8	71.5	71.6	72.4	70.1
5	68.6	69.7	72.3	73.4	73.9	75.1	72.3	73.7	71.6
6	73.0	67.7	69.6	73.7	70.7	70.4	71.1	72.9	69.7
7	70.9	68.4	72.4	72.9	73.1	70.9	70.9	73.0	70.5
8	67.0	67.4	69.3	72.0	70.7	70.2	70.6	71.4	71.1
9	68.8	65.4	69.3	73.6	72.5	70.2	70.9	72.7	69.7
10	69.8	68.4	70.6	70.8	70.5	68.5	69.2	71.4	70.6
11	67.7	70.8	72.5	71.6	70.0	72.9	71.5	71.1	68.7
12	67.0	68.3	69.2	70.4	69.4	69.7	69.9	71.7	71.0
13	70.0	68.9	71.5	72.3	72.2	70.4	69.6	71.8	69.7
23	68.5	70.9	70.8	73.2	71.6	69.7	70.8	72.3	69.9
24	72.8	71.6	70.3	70.9	71.5	71.7	70.4	72.9	71.0

Position	1k25 Hz	1k6 Hz	2k Hz	2k5 Hz	3k15 Hz	4k Hz	5k Hz	6k3 Hz	8k Hz
2	68.2	68.8	66.1	62.8	62.9	65.6	65.6	64.8	63.3
3	69.9	69.2	65.7	62.4	62.8	65.5	64.7	63.7	62.7
4	69.7	67.0	63.8	62.7	63.9	65.6	63.6	64.3	61.4
5	69.5	68.0	64.7	63.4	63.3	66.6	65.5	63.5	64.3
6	68.4	67.4	63.8	62.3	62.0	64.2	63.2	61.9	61.8
7	67.7	68.6	64.0	63.5	63.0	64.8	64.7	63.3	61.9
8	69.1	67.9	64.7	62.8	62.6	64.5	62.9	62.4	61.6
9	68.0	67.7	64.3	62.4	63.2	65.1	64.2	63.1	62.2
10	68.0	66.9	64.4	62.8	62.3	64.3	63.7	62.8	61.8
11	69.4	66.6	64.4	62.8	62.5	64.5	63.4	61.8	61.0
12	68.3	67.2	63.2	62.8	62.4	65.0	63.2	62.4	60.7
13	67.8	66.7	64.4	62.7	62.7	64.2	63.1	62.1	60.2
23	69.6	67.1	64.1	62.3	62.3	63.9	62.7	61.5	60.1
24	70.0	67.4	63.9	62.2	62.6	65.0	63.3	61.8	61.8

Position	10k Hz	12k5 Hz	16k Hz	20k Hz
2	62.2	58.8	56.1	50.6
3	61.3	58.0	55.4	50.4
4	59.8	57.0	53.9	47.7
5	61.3	59.6	57.2	51.5
6	60.7	57.9	55.3	49.4
7	61.2	57.1	55.4	47.8
8	59.9	56.3	53.0	47.5
9	60.5	56.0	52.9	46.3
10	59.4	56.7	53.3	46.5
11	58.7	54.5	50.3	42.6
12	59.2	55.1	51.7	44.8
13	58.0	53.6	50.6	43.7
23	58.6	54.9	49.7	44.5
24	59.9	56.4	53.5	46.7

1/3 Octave Band L_{eq} Measurements of the PA System at an output level of 90dBA

Position	20 Hz	25 Hz	32 Hz	40 Hz	50 Hz	63 Hz	80 Hz	100 Hz	125 Hz
2	58.1	66.8	67.6	76.2	78.6	72.5	71.7	75.3	82.0
3	53.9	64.1	70.1	80.3	77.9	72.4	76.0	76.8	80.0
4	50.1	56.9	70.1	79.4	75.5	77.4	73.4	74.4	75.8
5	52.7	62.0	61.9	72.7	74.4	73.7	71.5	74.9	79.9
6	53.1	61.0	66.3	71.5	71.7	78.0	69.1	76.8	80.8
7	54.4	59.3	64.6	71.3	73.8	75.2	71.1	74.5	78.9
8	54.6	65.7	66.3	77.1	78.9	72.0	73.4	76.9	76.5
9	55.1	62.0	69.0	79.8	78.2	77.8	71.1	78.6	79.4
10	57.5	57.1	64.2	78.0	77.1	76.4	72.7	70.8	76.7
11	56.3	63.9	68.2	79.6	78.4	79.7	74.1	76.8	76.9
12	56.4	60.1	69.7	80.0	75.3	78.6	75.2	77.6	78.2
13	58.8	55.4	68.7	78.4	77.7	76.4	71.5	78.8	78.3
23	58.0	68.1	67.3	77.4	77.1	73.7	75.3	76.9	81.6
24	53.9	60.9	70.1	75.6	81.9	78.9	77.8	75.9	82.9

Position	160 Hz	200 Hz	250 Hz	315 Hz	400 Hz	500 Hz	630 Hz	800 Hz	1k Hz
2	82.3	79.9	80.2	83.1	83.7	82.5	80.3	82.3	80.0
3	77.1	79.7	80.7	80.6	80.7	80.6	82.7	82.0	81.8
4	78.5	81.3	79.8	83.4	82.5	82.6	82.3	82.5	82.3
5	78.1	79.9	82.4	82.7	84.1	84.4	81.7	83.0	80.7
6	83.2	77.3	79.7	83.7	80.9	80.6	81.5	82.6	80.1
7	80.5	78.0	82.0	82.9	82.6	81.1	80.6	83.3	80.2
8	78.0	76.9	78.5	83.1	80.4	80.5	80.5	81.0	81.0
9	79.3	75.2	79.7	83.5	82.3	80.3	80.0	82.8	79.7
10	79.0	77.9	79.9	80.2	80.6	77.9	78.4	81.9	79.9
11	77.2	79.7	81.5	81.1	79.2	80.5	79.9	80.3	79.6
12	78.2	78.4	78.9	80.2	79.3	79.9	79.9	81.2	80.4
13	80.2	79.5	80.1	82.0	81.9	80.3	79.6	81.9	80.1
23	77.9	81.0	80.5	82.7	81.0	79.2	80.5	81.9	79.9
24	82.7	81.0	79.6	80.0	81.0	80.8	80.1	84.0	80.3

Position	1k25 Hz	1k6 Hz	2k Hz	2k5 Hz	3k15 Hz	4k Hz	5k Hz	6k3 Hz	8k Hz
2	79.2	78.3	76.4	73.9	74.1	76.1	75.2	74.6	73.2
3	79.3	79.0	75.9	73.7	74.0	76.0	75.2	73.7	72.3
4	79.5	79.2	76.2	73.9	73.4	75.3	73.7	72.8	72.4
5	79.2	78.3	75.4	74.0	74.5	76.4	74.1	75.4	73.5
6	79.1	78.6	75.2	73.6	73.0	76.1	74.7	74.1	71.6
7	78.2	78.8	74.7	73.5	73.2	76.8	74.5	73.5	72.0
8	78.9	78.5	75.2	73.2	72.9	74.7	73.7	72.8	72.0
9	78.0	78.3	74.5	73.4	74.2	75.3	74.1	73.1	72.5
10	78.1	77.5	74.3	72.9	73.9	75.0	73.8	73.5	71.7
11	78.9	76.8	75.4	73.0	72.9	74.7	73.7	72.3	71.1
12	77.7	76.6	73.4	72.4	73.2	74.9	73.3	72.5	70.7
13	78.6	76.8	74.0	73.2	73.5	74.3	73.1	71.8	70.6
23	79.8	77.4	74.0	72.4	73.2	74.5	72.7	71.7	70.3
24	78.3	79.1	74.1	72.5	73.8	75.3	73.9	72.8	71.6

Position	10k Hz	12k5 Hz	16k Hz	20k Hz
2	72.0	68.8	66.1	60.8
3	70.8	67.9	65.3	59.8
4	70.2	66.5	63.1	58.0
5	72.3	69.6	67.2	61.9
6	71.1	66.9	65.7	61.1
7	70.6	67.1	64.4	58.4
8	69.7	66.1	63.3	57.6
9	70.0	65.7	62.7	55.9
10	69.4	66.2	63.1	56.2
11	68.9	65.0	61.3	53.9
12	68.7	64.9	61.5	54.7
13	68.3	63.8	60.2	53.6
23	68.1	64.6	59.7	54.3
24	69.3	66.3	63.3	56.7

1/3 Octave Band L_{eq} Measurements of the PA System at an output level of 107dBA

Position	20 Hz	25 Hz	32 Hz	40 Hz	50 Hz	63 Hz	80 Hz	100 Hz	125 Hz
2	60.2	69.7	85.2	95.0	98.7	91.3	88.5	93.8	99.9
3	56.7	70.9	87.2	98.7	96.7	91.3	94.6	95.7	98.5
4	57.1	69.8	87.9	97.5	93.5	99.1	91.2	92.8	94.5
5	56.8	69.8	79.6	89.8	90.9	91.2	91.2	93.5	97.7
6	56.7	70.3	83.6	90.0	90.0	95.5	87.1	94.9	98.8
7	58.1	71.1	82.9	88.9	93.0	94.5	90.9	93.9	97.3
8	57.4	74.7	83.5	95.4	98.4	90.9	91.8	95.0	95.4
9	57.9	72.1	84.5	97.8	97.5	96.1	91.5	98.4	98.2
10	60.1	71.3	83.4	96.0	95.1	95.0	93.3	90.0	94.9
11	57.8	70.3	87.2	97.9	98.6	98.4	92.5	95.0	96.9
12	59.9	69.6	86.9	97.9	92.8	96.8	94.8	96.3	97.4
13	63.9	67.6	85.2	94.4	97.1	96.5	91.1	97.3	96.6
23	60.6	75.2	85.1	95.7	95.3	92.2	94.8	95.9	100.5
24	59.7	71.8	88.7	94.1	102.5	99.7	97.1	94.4	100.8

Position	160 Hz	200 Hz	250 Hz	315 Hz	400 Hz	500 Hz	630 Hz	800 Hz	1k Hz
2	99.7	98.1	97.0	100.8	101.0	100.8	96.9	100.0	99.2
3	95.1	97.4	98.2	98.4	98.2	98.8	101.5	99.9	99.3
4	97.0	97.9	98.0	101.8	100.8	100.0	100.2	99.6	98.8
5	96.4	96.4	100.2	100.6	101.4	101.7	99.4	99.6	98.1
6	102.0	96.3	97.4	101.0	98.4	98.0	99.0	100.1	97.9
7	99.2	96.8	100.4	101.6	100.2	98.1	98.2	100.2	97.7
8	96.7	95.1	95.4	100.1	98.4	99.0	98.5	98.7	97.0
9	96.8	93.1	96.4	100.9	100.0	97.8	98.0	100.5	98.0
10	97.5	95.5	97.3	98.6	98.1	95.9	96.5	99.6	97.8
11	95.5	98.9	99.1	98.2	96.5	99.5	98.2	97.3	97.7
12	96.1	96.6	97.4	98.2	96.7	98.4	97.3	98.8	98.1
13	98.1	96.3	98.2	100.1	99.8	97.5	96.7	99.1	97.9
23	96.2	98.7	98.7	100.4	99.1	98.4	98.4	100.0	97.2
24	100.5	99.5	97.6	98.7	99.5	99.1	97.7	101.0	98.2

Position	1k25 Hz	1k6 Hz	2k Hz	2k5 Hz	3k15 Hz	4k Hz	5k Hz	6k3 Hz	8k Hz
2	96.5	95.7	93.8	92.0	91.0	93.7	93.0	92.2	90.5
3	96.9	97.4	92.4	91.6	91.9	93.4	92.5	91.2	89.8
4	96.1	94.8	92.2	92.1	92.2	93.3	91.2	91.2	89.1
5	97.0	97.1	92.6	91.7	92.1	94.4	93.6	91.6	90.9
6	96.8	96.1	92.2	91.6	90.3	93.4	92.5	91.1	90.2
7	96.7	96.5	92.5	92.1	91.9	92.1	92.3	91.6	89.5
8	96.6	96.1	92.8	91.3	91.4	92.1	90.9	90.0	88.4
9	95.5	95.9	92.6	90.8	91.2	93.3	91.8	90.8	90.0
10	96.3	95.3	92.3	91.3	91.7	92.5	91.4	90.7	89.5
11	96.9	94.9	92.7	90.6	90.7	92.0	91.0	89.7	88.3
12	96.2	94.4	91.8	90.7	90.9	92.6	91.0	90.2	88.2
13	95.8	94.8	91.7	91.1	91.1	92.3	90.4	89.5	87.6
23	97.6	95.8	92.7	90.7	90.6	91.3	90.4	89.4	87.6
24	98.0	96.2	92.5	90.8	91.4	92.8	90.9	89.9	89.2

Position	10k Hz	12k5 Hz	16k Hz	20k Hz
2	89.4	86.2	83.6	78.5
3	88.4	85.3	82.6	77.4
4	86.5	83.5	80.5	74.8
5	89.3	86.2	84.3	78.9
6	89.1	83.7	82.5	77.2
7	86.9	85.0	81.9	75.3
8	86.0	82.5	78.9	72.9
9	87.4	83.3	79.9	73.3
10	87.0	83.8	80.0	73.4
11	86.0	82.4	78.2	71.0
12	86.0	82.3	78.9	72.2
13	85.3	81.0	77.7	71.1
23	85.7	82.4	76.9	72.3
24	86.8	83.8	81.0	74.7

1/3 Octave Band L_{eq} Measurements of the DJ Monitor at all Output Levels

Output Level	20 Hz	25 Hz	32 Hz	40 Hz	50 Hz	63 Hz	80 Hz	100 Hz	125 Hz
80	59.5	66.1	53.3	55.1	64.4	64.4	62.1	59.2	56.6
90	60.4	65.9	54.2	58.5	68.8	71.1	71.2	67.6	65.1
100	59.5	66.8	59.2	69.6	78.5	83.6	82.0	78.2	75.5
110	65.4	70.9	68.1	76.5	85.2	90.9	90.5	88.8	86.3

Output Level	160 Hz	200 Hz	250 Hz	315 Hz	400 Hz	500 Hz	630 Hz	800 Hz	1k Hz
80	65.3	69.3	69.4	66.8	67.6	64.7	62.4	63.3	70.2
90	74.8	79.5	78.9	75.8	76.2	74.4	72.1	73.9	79.4
100	85.0	88.8	89.7	87.0	87.7	84.4	81.7	83.4	90.1
110	97.3	100.2	98.2	95.8	94.6	95.2	92.7	94.3	101.3

Output Level	1k25 Hz	1k6 Hz	2k Hz	2k5 Hz	3k15 Hz	4k Hz	5k Hz	6k3 Hz	8k Hz
80	73.2	73.5	65.7	67.3	68.0	67.4	66.1	66.4	65.9
90	83.6	82.2	75.0	76.9	77.1	77.2	75.3	76.0	75.6
100	94.7	93.6	87.1	87.4	87.8	87.7	86.7	86.8	86.2
110	102.6	102.3	95.4	96.5	97	97.6	96.2	96.2	96

Output Level	10k Hz	12k5 Hz	16k Hz	20k Hz
80	64.1	62.7	62.6	48.2
90	74.2	73.0	73.8	59.2
100	84.6	83.8	83.6	70.1
110	94.6	93.6	94.4	80.4

Broadband LA_{eq} and Octave Band L_{eq} Measurements of the Background Noise

Position	LAeq	16 Hz	32 Hz	63 Hz	125 Hz	250 Hz	500 Hz	1k Hz	2k Hz	4k Hz	8k Hz	16k Hz
12	52.6	59.9	64.8	62.1	63.6	51.2	48.5	49.3	41.0	33.5	25.4	17.9
24	51.3	64.8	66.3	62.2	56.5	49.6	49.2	47.1	42.2	32.9	25.0	18.1

4. Source and Receiver Coordinates for the RT Measurements

Source/Receiver	X(m)	Y(m)	Z(m)
S1	4.37	12.1	1.64
S1	7.3	2.3	1.2
S3	17.04	3.28	1.2
S4	18.66	9.88	1.2
R1	5.6	9.8	1.5
R2	10	13.8	1.5
R3	13.7	12.3	1.5
R4	1.1	7.7	1.9
R5	5.6	6.3	1.5
R6	5.6	2.3	1.5
R7	1.4	1.3	1.5
R8	10	2.5	1.5
R9	10	7.6	1.5
R10	14.9	2.5	1.5
R11	20.3	1.7	1.7
R12	18.6	7.5	1.5