ArupAcoustics

Chetham's School of Music

**New Music School Building**

Stage D Report

Report ref
AAc/121463-00/R02

**ISSUE 2**

26 APR 2007

ArupAcoustics

# Chetham's School of Music

## New Music School Building

Stage D Report

March 2007

**Arup Acoustics**
8th Floor St James's Buildings, Oxford Street, Manchester M1 6EL
Tel +44 (0)161 228 2331 Fax +44 (0)161 906 3212
www.arup.com/acoustics

This report takes into account the particular instructions and requirements of our client. It is not intended for and should not be relied upon by any third party and no responsibility is undertaken to any third party

Job number 121463-00

| | | | |
|---|---|---|---|
| Job title | New Music School Building | Job number | 121463-00 |
| Document title | Stage D Report | File reference | 2 |
| Document ref | AAc/121463-00/R02 | | |

| Revision | Date | | | | |
|---|---|---|---|---|---|
| ISSUE 1 | 05/03/07 | Filename | R02_SJS (Issue 1).doc | | |
| | | Description | First issue | | |
| | | | Prepared by | Checked by | Approved by |
| | | Name | Steven Swan BEng MIOA MIEE | Raf Orlowski BSc(Eng) PhD CEng MIEE FIOA | Raf Orlowski BSc(Eng) PhD CEng MIEE FIOA |
| | | Signature | | pp | pp |
| ISSUE 2 | 13/03/07 | Filename | R02_SJS (Issue 2).doc | | |
| | | Description | Second issue, to coordinate with the design of the Architect and Structural Engineer | | |
| | | | Prepared by | Checked by | Approved by |
| | | Name | Steven Swan BEng MIOA MIEE | Raf Orlowski BSc(Eng) PhD CEng MIEE FIOA | Raf Orlowski BSc(Eng) PhD CEng MIEE FIOA |
| | | Signature | | pp | pp |
| | | Filename | | | |
| | | Description | | | |
| | | | Prepared by | Checked by | Approved by |
| | | Name | | | |
| | | Signature | | | |
| | | Filename | | | |
| | | Description | | | |
| | | | Prepared by | Checked by | Approved by |
| | | Name | | | |
| | | Signature | | | |

Issue Document Verification with Document ✓

## Contents


| | | | Page |
|---|---|---|---|
| Executive Summary | | | 1 |
| Summary for Planning Submission | | | 1 |
| 1 | Introduction | | 2 |
| 2 | Acoustic Quality Goals | | 2 |
| | 2.1 | Concert Hall | 2 |
| | 2.2 | Recital Hall | 3 |
| | 2.3 | Practice Rooms | 3 |
| | 2.4 | Music Technology Areas | 4 |
| | 2.5 | Background Noise Levels | 4 |
| | 2.6 | Sound Insulation Requirements | 4 |
| 3 | Noise Survey | | 5 |
| | 3.1 | Intrusive Noise | 5 |
| | 3.2 | Plant Noise Criteria | 5 |
| 4 | Design Concepts | | 5 |
| | 4.1 | Sound Insulation | 5 |
| | 4.2 | Vibration Isolation | 7 |
| | 4.3 | Surface Finishes | 7 |


## Appendices


Appendix A

Acoustic Terminology

Appendix B

Preliminary Guidance on Noise Control for the Building Services Installation

Appendix C

Noise Survey

## Executive Summary

Chetham's School of Music is proposing a new music teaching building which will contain a concert hall, a recital hall, practice rooms, ensemble rooms, recording facilities, academic classrooms and ancillary spaces. Many of these spaces have critical acoustic requirements, and so the acoustic design of this building will be important to its success.

This report summarises the progress of the acoustic design up to RIBA Stage D. There has been significant progress in the acoustic design of the building, the key areas are summarised as follows:

- The overall construction of the concert hall has been developed to provide it with a double structure, with its inner structure being completely isolated from the ground and the rest of the building (similar to the approach taken at the Bridgewater Hall). This type of construction should be able to minimise noise due to tram / train vibration, and also provide a very high degree of sound reduction between the hall and the rest of the building.
- The overall geometry of the concert hall has been optimised (eg increased ceiling height, improved balcony design etc) to provide the basis of an excellent room acoustic. Similar comments apply to the recital hall; the key improvements for this space are that it has been developed to provide a more rectangular geometry with a greater ceiling height.
- A detailed noise survey has been carried out to inform the design of the building façade to control intrusive noise levels (eg road traffic etc) and also to set environmental noise criteria for plant associated with the building.

Generally, the planning of the spaces and their overall geometry is developing well and refinements in the design to meet suitable acoustic requirements are progressing. Significant further work is required during future design phases to refine the design to ensure that the acoustic intentions are achieved.

The design at Stage D has the potential for providing an excellent music teaching building for Chetham's.

## Summary for Planning Submission

The acoustic design of the new Chetham's music teaching building is key to its success, and the Client requires very good acoustic standards throughout. The design of the building is very complex and requires further significant analysis and development to ensure that the high standards are achieved. What follows is a summary of the key acoustic issues relating to planning:

**Plant Noise.** A detailed noise survey has been carried out at the site and noise criteria have been set for all plant associated with the building, in line with Local Authority requirements (please refer to section 3).

**Noise Ingress.** Due to the relatively high external noise levels (eg road traffic etc) a high standard of sound insulation will be provided to all acoustically critical spaces (eg Concert Hall, Recital Hall, Recording Studios, Music practice rooms etc). To achieve these standards it will be necessary to employ a 'box in box' type of construction for these spaces, where the internal 'box' or 'room' is mounted on anti-vibration bearings to isolate it from the outer 'room' / building (please refer to section 4.1). This type of construction can provide very high standards of sound insulation, and is also essential to minimise noise transfer within the building (eg noise from classrooms directly above the concert hall affecting a critical performance etc).

These spaces have also been 'cocooned' within the building as far as possible and do not have single external doors. Any entrances to these spaces will be via Sound Lobbies, which will comprise acoustic doors separated by a short lobby with acoustically absorbent finishes.

Target internal background noise levels are given in Table 1.

**Noise Egress.** The acoustically critical spaces discussed above are also capable of producing high sound levels (eg an orchestral rehearsal in the concert hall etc). However, since these spaces will have high performance constructions to control noise ingress, these constructions will also significantly reduce noise egress, ie noise produced in these spaces affecting nearby noise sensitive areas (residential etc).

# 1 Introduction

The following report summarises the acoustic design up to RIBA Stage D for the proposed new music teaching building for Chetham's School of Music.

Chetham's School of Music is proposing to build a new building which will contain a concert hall, a recital hall, practice rooms, ensemble rooms, recording facilities, academic classrooms and ancillary spaces. This report describes the current status of the design in terms of acoustics, noise control and vibration isolation. In particular, it covers the following areas:

- Room acoustics of spaces
- Sound insulation to and from the environment
- Sound insulation between adjacent spaces within the building
- Noise and vibration levels from building services

A list of the acoustic terminology used in this report is included in Appendix A. Preliminary guidance on noise control for the building services installation is given in Appendix B. A report on the detailed environmental noise survey carried out around the site is given in Appendix C.

# 2 Acoustic Quality Goals

## 2.1 Concert Hall

### 2.1.1 Introduction

The design of the concert hall has progressed well and the overall geometry shown by the current proposals should be capable of achieving an excellent acoustic. The acoustic design has been informed by initial computer modelling and extensive experience of these types of spaces. Some of the key developments are:

- The design of the balcony has been optimised to reduce the number of seats it overhangs.
- The ceiling height has been increased to in excess of 12m. This is critical for this type of space to provide the appropriate reverberation time.

### 2.1.2 Uses

The Client has confirmed that the concert hall is to be designed with no compromise regarding its primary use, namely recital, chamber music and chamber orchestra performance and rehearsal. In this mode audience capacity is to be around 340.

The Client requires the concert hall to be made compatible with larger orchestral forces, primarily for rehearsal. Due to the size of the hall, its acoustics will not be optimal for large orchestras, and loudness levels will be higher than desirable and reverberance lower than desirable.

The hall would also be used for amplified performance (eg amplified jazz, corporate events with AV equipment etc) and so would require a method of reducing its reverberation time for such events. The option of achieving this 'variable acoustic' with movable drapes is considered acceptable by the Client. These drapes may also be used to reduce the loudness in the hall due to large orchestra rehearsals.

### 2.1.3 Acoustical Quality Goals

Specific acoustical goals for the Concert Hall are listed below. It is important that the Hall is successful in achieving all the stated goals, as they all contribute to a unified listening experience.

Absence of background noise is essential to allow artists freedom to play or sing extremely quietly without distraction. The sound of the performance is cleaner and more exciting when there is no audible background noise. *A background noise level of PNC15 is recommended although a higher level of NR20 may be acceptable.*

Ample loudness, strength, impact. The design will pay particular attention to providing ample loudness over the whole seating area. *A target range for the loudness parameter, G, is 6.0 to 10.0dB with a maximum range across the room of 4dB.*

Good clarity and definition. Recitals and chamber music benefit from a high degree of clarity and definition. *The Clarity Index should fall in the range -2.0dB to +2.0dB.*

Appropriate low frequency strength and warmth of tone. The Concert Hall should have strength and impact in the low frequency (bass) range to transmit the visceral excitement of the bass drum and tympani, the palpable "thump" of double bass and celli pizzicato, the strength of the tuba. It must also achieve an overall warm tone colour for the strings and each of the other sections. Although the bass should be strong, it should not be so strong or uncontrolled that it creates a muddy sound. *Low frequency Reverberation Time (RT) should be within 115% to 120% of mid-frequency RT.*

Excellent envelopment and spatial impression. This is a sensation that one is enveloped by sound as opposed to hearing it from a mainly frontal direction. Listeners feel acoustically close to the performance and indeed part of it which is vitally important for chamber music. *Early Lateral Energy Fraction should be in the range 0.25 to 0.35.*

Appropriate reverberance and liveness. A listener's sense of the sound lingering in the hall has several attributes:

Length of sound decay

Level (loudness) of decay

Level of running reverberance (influences "blend")

Achieving simultaneously a high degree of both clarity and reverberance is possible and desirable. *The mid-frequency RT should be in the range 1.4s to 1.8s when occupied.*

Appropriate balance over the frequency spectrum, i.e. the loudness of high, mid and low frequencies should be in a pleasing balance. The violin tone should be warm, not scratchy. The brass tone should be warm when desired and brilliant when desired. Both performers and audience want to hear an excellent rendition of the tonal quality of the various instruments and voices. The effort that performers put into their artistry should come across to the audience; i.e. the tone of instruments and voices should not be altered by the room, they should sound natural.

Excellent balance between the various sections of an orchestra or chorus (or both together). This is highly dependent on the performers and the conductor, but the acoustics of the hall should make it easier for the conductor and players to achieve the desired balance out in the hall. The conductor and musicians must hear each other in an appropriate balance so that they can judge how their sound is balanced in the audience area.

Excellent balance between soloists and ensemble. Much of an audience attends a solo performance to hear and see the soloist, so people are generally more aware of this specific acoustical concern than of other concerns. The conductor and musicians have a major part to play in achieving excellent balance, but the hall can make it relatively easy or difficult for them.

Good hearing conditions on stage. Musicians must hear each other well to achieve excellent ensemble. Temporal precision and pitch precision are vitally important. The Hall must provide multiple sound reflections at appropriate times for the musicians to hear each other. *The support index, ST1, on stage should be in the range -13dB to -10dB.*

Excellent support for each performer's own sound so that one senses that the sound is carrying to the rear of the hall. This involves particularly the loudness and reverberance of the sound returning to the performers. When musicians feel the room working with them, they can relax and perform better. Musicians dislike halls where they feel they have to "force" their sound.

Avoidance of Acoustical Deficiencies.

Avoidance of roughness and harshness, stridency, distortion, boominess, and other unnatural or unpleasant colouration of the frequency balance.

Avoidance of "dead areas" which are symptoms of poor distribution of sound.

Avoidance of echoes or muddiness which are caused by long-delayed discrete sound reflections.

#### 2.1.4 Overall shaping and geometry

Set out below are comments on the current drawings of the concert hall.

#### 2.1.4.1 Width

A width of 17m in the middle is close to recommended values for this size of hall. The stage splay of around 10 degrees is also beneficial.

#### 2.1.4.2 Height

The design has progressed to provide a height in excess of 12m. This is very important for this type of hall, to enable the sound to rise up and provide a reverberant sound field above the audience.

#### 2.1.4.3 Stage

The stage appears very deep for this type of hall. This has been explored further and is understood to be a requirement of the Client (ie to accommodate a large orchestral rehearsal). The main issue with such a large stage is that smaller groups of players would appear 'lost', and their performance might lack intimacy both acoustically and visually. To mitigate this as far as possible moveable screens / reflectors will be developed during the next design phases.

#### 2.1.5 Surface Finishes

The materials of the hall will be massive to give acoustical strength and warmth. This means concrete or masonry with acoustically suitable finishes. These finishes will be plaster or timber for the walls and ceiling or a mixture of both, timber flooring and a timber stage.

Seating will be carefully specified in terms of acoustical absorption and provision will be made in the programme for laboratory testing to show compliance with the specification.

#### 2.1.6 Further Work

The design of the hall requires further significant detailed analysis to ensure that the acoustic aspirations will be achieved. Typical key issues are to:

- Optimise the main surfaces in the hall to provide the necessary sound reflecting and diffusing properties,
- Develop the design of the technical gallery, and in particular any reflectors required to its underside (ie the 'architectural' ceiling),
- Develop the design of any reflectors over the stage to provide reflections back to performers,
- Incorporate the required areas of retractable acoustic absorption to cater for amplified performances,
- Develop suitable methods to reduce the stage size (eg screens etc).

## 2.2 Recital Hall

#### 2.2.1 Uses

The Client has confirmed that the primary uses of this hall will be solo instrument performances, string quartets, small chamber ensembles and sectional orchestra rehearsals. As with the Concert Hall, its acoustics should also be compatible with amplified performances, and so a method of reducing the reverberation time of this space will be developed.

#### 2.2.2 Acoustical Quality Goals

Excellence in all the acoustical qualities described for the Concert Hall is also required in the Recital Hall. The reverberance will be shorter and Reverberation Time values in the range 1.2s to 1.5s are proposed. The option of reducing the reverberation time (ie for amplified performance) with movable drapes is considered acceptable by the Client.

#### 2.2.3 Overall Geometry

The previous design of this space was rather square, and the design has been progressed to achieve a more rectangular geometry which is more desirable acoustically. It has been possible to increase the height of this space which is also acoustically desirable. As with the concert hall, further detailed analysis and design is required to achieve the optimum acoustic for this space.

## 2.3 Practice Rooms

#### 2.3.1 Uses

There are a range of different sizes of practice rooms which will accommodate individual practice and teaching. Any particularly noisy rooms such as those for percussion and amplified music need to be identified as they will require additional sound insulation.

#### 2.3.2 Acoustical Quality Goals

Practice rooms require a controlled reverberance which should be provided by a Reverberation Time in the range 0.4s to 0.8s. It is beneficial for most practice rooms to have a degree of variability so that loudness and reverberance can be controlled to some extent. This can be adjusted to suit different instruments and also to provide different rehearsal conditions, ie a dry or live acoustic.

#### 2.3.3 Geometry

The plan area of practice rooms is critical and should not fall below 8m² for the small ones. The minimum height is 2.7m and greater heights than this are beneficial. It is advantageous to have non-parallel walls to break-up strong room modes but additional modelling of the walls is also recommended. This can be in the form of acoustic wall panels.

## 2.4 Music Technology Areas

### 2.4.1 Uses

Following discussions with the Client it is understood that the key acoustically critical spaces are: the performance area 1.011, the control room 1.010, and booths 1.102 and 1.013. It is understood that the Client will also use room 1.014 as their main edit room and so require this to be designed to a similar acoustic standard as the control room 1.010. The acoustic requirements for the other spaces in this area are as follows:

- Midi Suites (1.018 & 1.019) – These are open plan classroom-type spaces, and so do not require 'box in box' constructions,
- Room 1.017 will be a typical office space,
- Rooms 1.015 and 1.016 are not as acoustically sensitive as the studio areas, and so will not require such high performance constructions and finishes. However, they should be provided with good acoustic doors and acoustically absorbent finishes to control their room acoustic.

### 2.4.2 Acoustical Quality Goals

The reverberation time of the control room, performance area and edit room needs to be strictly controlled, and we would propose a target of less than 0.3s for the control room and edit room, and 0.5 to 1.0s for the performance area. It may be desirable to have a simple variable acoustic in the performance area to accommodate different types of instruments/performance, and also for teaching purposes.

In order to achieve the reverberation time requirements, acoustically absorbent wall and ceiling finishes will be required. At this stage we suggest that a zone of 200mm be allowed for on the walls of these spaces to accommodate these treatments. Detailed calculations will be required to determine the type and area of treatments required, however, it may be possible to reduce the depth of finishes zone to some walls.

### 2.4.3 Geometry

The minimum height for the performance area is 2.7m (internal clear height), although greater heights could be beneficial. It is also advantageous to have non-parallel walls in this space together with the control and edit rooms to break-up strong room modes. It may be necessary to increase the overall floor area of the control room slightly to accommodate the required acoustic finishes (discussed in section 4.1.6). The finishes zone is in addition to the wall construction required for sound insulation purposes.

## 2.5 Background Noise Levels

Target noise criteria for typical spaces are proposed in Table 1. These criteria apply to the total noise level in each space (eg intrusive noise, services noise etc), in furnished but unoccupied spaces.

In subjective terms, a typical services noise level at PNC15 (Perceived Noise Criterion) is inaudible under most conditions, at NR20 (Noise Rating) the services noise level would be faintly audible to discerning listeners, and at NR30 the services noise level would be audible to most listeners.

| *Space* | ***Typical noise criterion*** |
|---|---|
| Concert Hall and Recital Hall | PNC15 / NR20 * |
| Sound recording studio (Control Room, Performance Area & Edit Room) | PNC15 / NR20 * |
| Large music practice rooms & Ensemble rooms (assumed not to be used for critical recordings) | NR25 |
| Small music practice rooms | NR30 |
| Small offices | NR35 |
| Open plan offices | NR38 |
| Toilets, stores etc | NR40/45 |

**TABLE 1:** Typical target internal noise criteria

* These criteria should only be treated as preliminary, and may need to be revised as further analysis / investigations take place.

Preliminary guidance on noise control for the building services installation is given in Appendix B.

## 2.6 Sound Insulation Requirements

Internal sound insulation is critical in the acoustic design of a music teaching building, therefore the partitions between spaces must be designed with due regard for the typical use of each room. This includes elements within the partitions like doors and windows. Table 2 gives recommended values of weighted level difference $D_w$ for various adjacencies.

| Room Adjacency | | Minimum Sound Level Difference $D_w$ |
|---|---|---|
| Concert Hall | Foyer | 55 dB |
| Practice Room | Practice Room | 60 dB |
| Sound recording studio/control room | Corridor | 65 dB |
| Sound recording studio | Control room | 60 dB |
| Practice Room | Corridor | 40 dB |
| Academic Classroom | Academic Classroom | 45 dB |
| Academic Classroom | Corridor | 40 dB |

**TABLE 2:** Weighted level difference between adjacencies

# 3 Noise Survey

Arup Acoustics has carried out a detailed noise survey around the site of the proposed new building. The purpose of the survey was to establish typical:

- external noise levels, to assess the requirements for the external building fabric and achieve suitable internal noise levels (eg due to road traffic noise etc).
- background noise levels at noise sensitive areas close to the site (dwellings etc), to set environmental noise criteria for any building services plant associated with the building.

Full details of the survey procedure and results are given in Appendix C.

## 3.1 Intrusive Noise

A summary of typical external noise levels is given in Figure 1.

As can be seen from Figure 1 external noise levels are of the order of 70 $dBL_{Aeq}$ and up to around 90 $dBL_{Amax}$, at facades fronting Victoria Station Approach and Hunt's Bank. These noise levels are relatively high, and so high performance constructions will be required for the external building envelope to achieve suitable internal noise levels.

Outline advice is provided in the following sections on measures to control intrusive noise levels to achieve the proposed background noise criteria. This needs to be developed during future design stages.

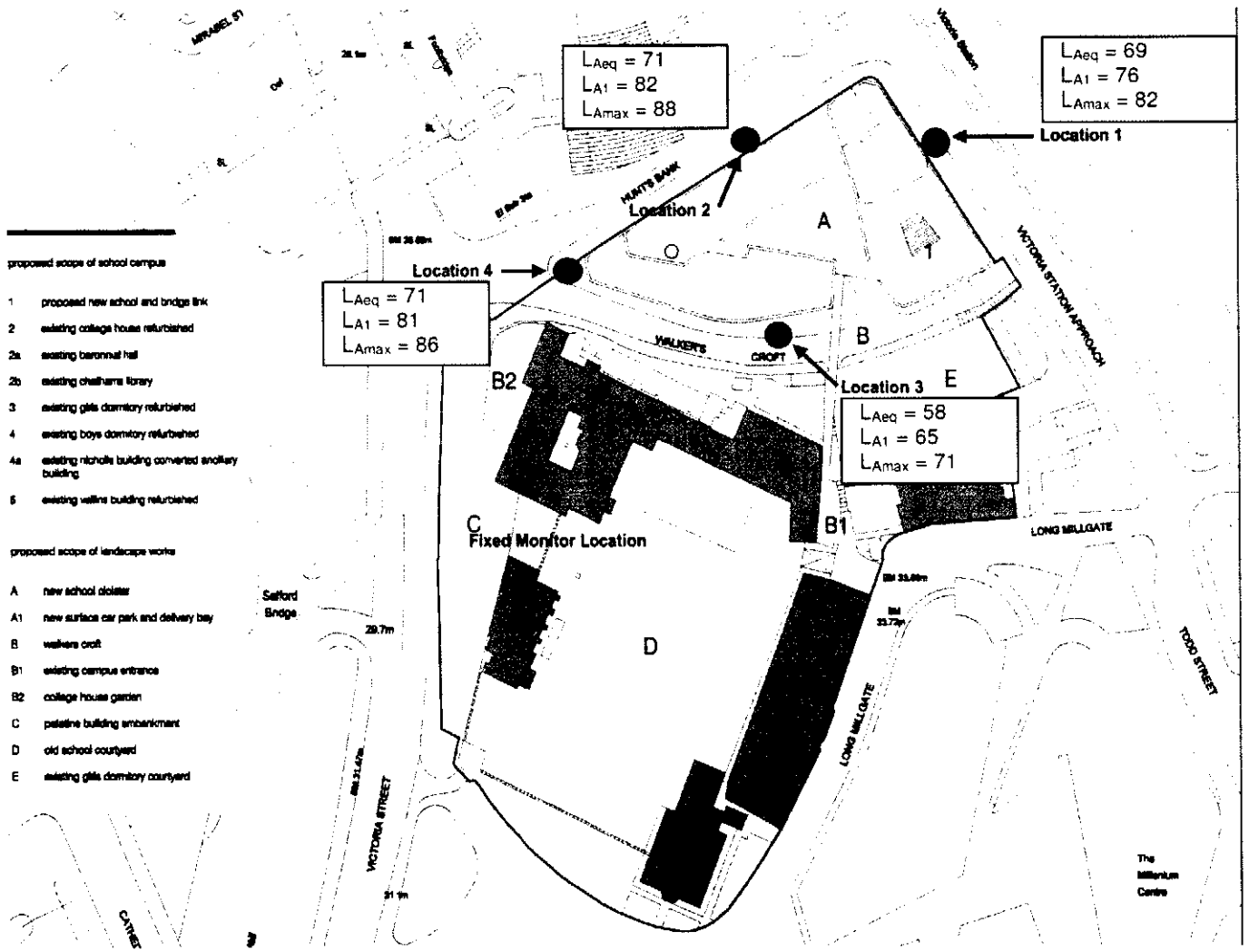



**FIGURE 1:** Typical external noise levels

## 3.2 Plant Noise Criteria

It is important that the noise of any externally mounted building services equipment and air intake and exhaust louvres does not cause disturbance to any nearby noise sensitive areas (eg dwellings, the school etc). Arup Acoustics has contacted the Environmental Health Department at Manchester City Council and understands that their criteria for plant noise are as follows:

- The total $L_{Aeq}$ plant noise level must be at least 5 dB below the pre-existing $L_{A90}$ background noise level at 1m from the façade of any nearby noise sensitive areas. If any of the noise emissions exhibit an identifiable noise character (eg tonality, impulsiveness, intermittence etc) the limits shall be reduced by a further 5 dB.

From the environmental noise survey, the minimum $L_{A90}$ free-field noise levels measured at the site are as follows:

- 46 $dBL_{A90}$ Daytime (07:00 to 23:00hrs)
- 43 $dBL_{A90}$ Nighttime (23:00 to 07:00hrs)

Therefore, based on the above, the maximum noise criteria would be as follows:

- 41 $dBL_{A90}$ Daytime (07:00 to 23:00hrs)
- 38 $dBL_{A90}$ Nighttime (23:00 to 07:00hrs)

These criteria should be reduced by a further 5dB in the event of any plant items exhibiting an identifiable noise character (eg tonality, impulsiveness, intermittence etc).

# 4 Design Concepts

## 4.1 Sound Insulation

### 4.1.1 Main Concert Hall

Arup Acoustics has previously suggested the following options for the construction of this space:

1. Completely independent 'floating' structure. This is a similar principle to the rehearsal rooms (Sketch 1), where the internal structure is completely independent of the main building structure (ie does not have any rigid contact with the outer structure). This option should be able to achieve a very high degree of sound reduction between the hall and surrounding areas.

2. Partially independent structure. With this option the inner structure would be supported off the main building structure, possibly with independent elements (eg an independent ceiling construction etc). This option could provide a good degree of sound reduction between the hall and surrounding areas. However, this would generally be lower than option 1, and so a greater degree of building management would be required (eg it may not be possible to use the classrooms above the hall during a critical recital etc)

It is understood that the Client requires option 1, to give the maximum flexibility in the use of the auditorium and building. This option should be able to provide a very high degree of sound reduction to both sound entering (eg noise from the classrooms above etc) and leaving the auditorium (ie concert sound affecting nearby external areas, such as residential etc). Also, this option would be able to minimise any noise in the auditorium due to vibration from the nearby rail and tram ways (please refer to section 4.2).

The design of the auditorium has progressed well to achieve the inner 'floating box' within, and completely independent of, the overall building structure. The current proposals are for this inner box to have a 150mm dense concrete floor with 140mm dense blockwork walls and a 150mm dense concrete 'lid'. It is important to maintain a clear cavity of at least 200mm between the outer and inner 'floating' structure.

#### 4.1.2 Recital Hall

The location of this space has changed since our Stage C report (dated 24/10/06). For the previous scheme three main options for the sound insulation of this space were discussed with the Client, and it was decided that a floating 'box in box' type construction would be adopted (ie similar to the concert hall) with plasterboard walls and ceiling. The current location of this space is more suitable acoustically (ie there is no longer a car park below, or external circulation space above), and so the proposed construction should also be suitable for this location.

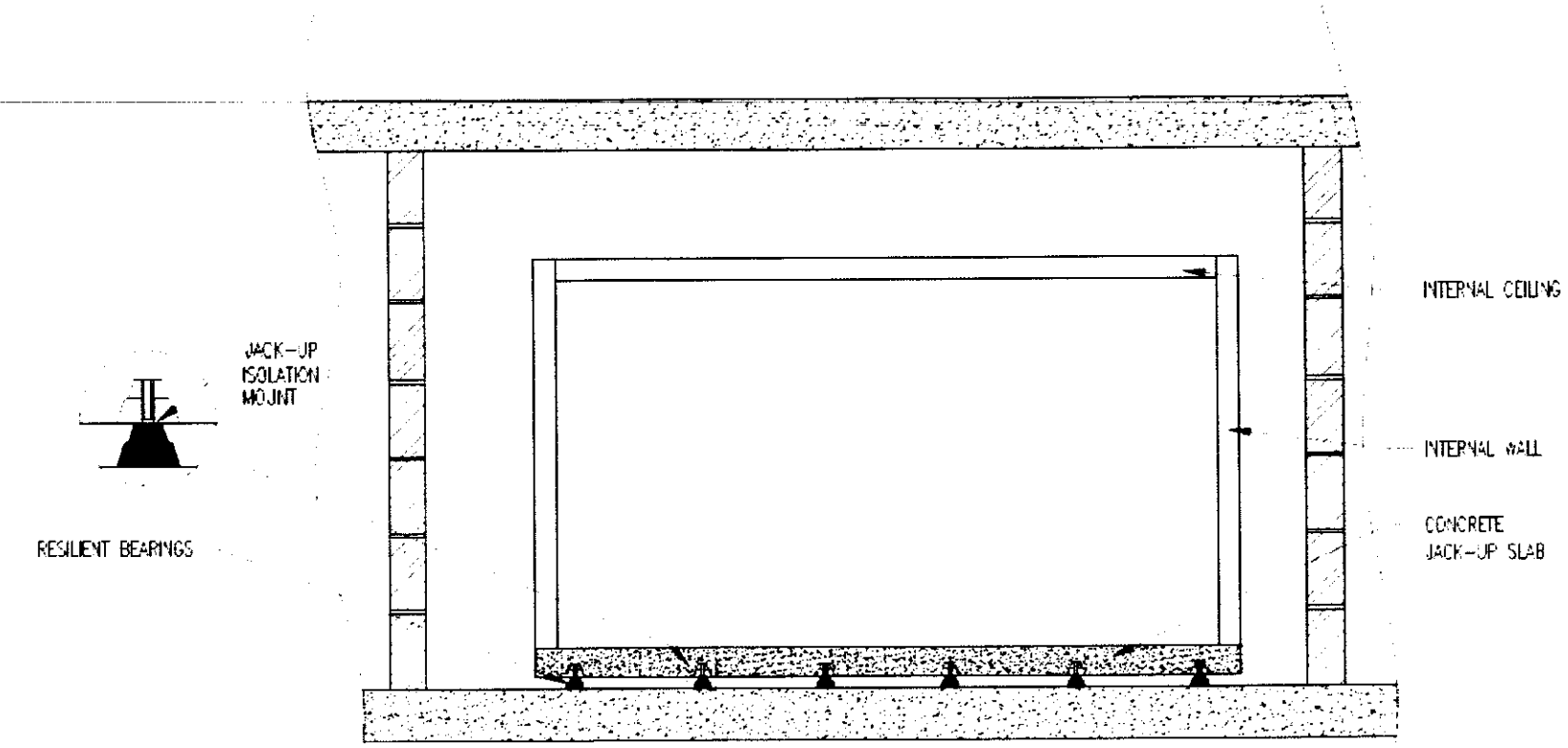
The current proposals are to have fixed outer walls (typically 140mm dense blockwork), and an inner 'floating box' consisting of a concrete floor, on top of which the plasterboard walls and ceiling will be constructed (these will typically consist of three sheets of acoustic grade plasterboard, overall mass of around 38kg/m$^2$). It may be possible to suspend the ceiling from the fixed concrete soffit providing a suitable suspension method is used (eg resilient hangers etc).

#### 4.1.3 Small Music Practice Rooms

The sound insulation requirements for these spaces have been discussed with the Client. Due to the high levels of room to room sound insulation required, it will be necessary to provide these spaces with a 'box in box' construction. Generally this will involve constructing a 'floating' floor (eg typically a concrete slab supported on resilient bearings) on top of which the room's plasterboard walls and ceiling will be built (as shown in Sketch 1). The aim is to have no rigid contact between the internal 'floating' room and the rest of the building structure.

Since there is a large number of music practice rooms the cost of providing each one with a full 'box in box' construction could be very high, and this is possibly not necessary if some of the rooms are to be used for 'quieter' instruments. It should be possible to reduce the specification for these types of rooms and provide them with more standard fixed partitions (eg standard blockwork separating walls etc) and possibly plasterboard linings (eg suspended plasterboard ceilings etc). An analysis of the room useage will be carried out during the next design phase, and a construction type (ie standard or full 'box in box' construction) will be agreed with the Client.

Due to the high external noise levels, a high performance double window type of construction will be required for these rooms, with the external window fixed to the outer structure and the internal window fixed to the inner floating box as discussed in our Stage C Stage C report (dated 24/10/06).




**SKETCH 1** – Typical sketch of a 'box in box' construction

#### 4.1.4 Large Music Practice & Ensemble Rooms

The construction requirements for these spaces will be similar to the small music practice rooms. However, given that these spaces will be used for groups of musicians, their sound levels will be higher and so all of these spaces are likely to require a full 'box in box' construction (as shown in Sketch 1). Also a similar external wall construction is proposed for these spaces; however, since they have more stringent noise criteria, it is likely to be necessary to increase the cavity between their windows to at least 150mm.

#### 4.1.5 Academic Teaching Classrooms

Generally these spaces will require separating walls capable of achieving $D_w45$, which would typically require the following partition constructions:

- 2 x 12.5mm plasterboard each side of a 70mm metal stud (total width 122mm) with a lining of 50mm glass wool in the cavity, OR 140mm medium density block (min 1500kg/m$^3$) plastered to 12mm both sides.

In terms of the external wall / glazing construction (ie to control intrusive noise), the requirements will be similar to those for the small music practice rooms (ie external window/100mm airspace/internal window). It may be possible to achieve the requirements with a single high performance double glazed unit; further advice on this will be provided as necessary.

The external noise levels are generally lower on the Walkers Croft façade and so the acoustic requirements for this façade will be lower.

#### 4.1.6 Sound Studio and Main Edit Room

These spaces (1.011, 1.010 and 1.014) will need to be constructed from full 'box in box' constructions, as shown in Sketch 1. There are two options for the walls and ceiling of these rooms: 1) dense blockwork walls with a concrete lid (similar to the concert hall), or 2) plasterboard walls with a plasterboard lid. Of both options 1) is capable of achieving the highest degree of sound reduction, although it is important to note that both options can achieve good sound reduction and should be able to provide a good standard of studio. Each option will be considered in detail during the next design phase, in conjunction with a cost analysis and Client comment.

Although the above proposals should both be able to provide a high degree of sound insulation for these rooms, there are music practice rooms directly below. It may therefore be necessary to exercise a degree of management over these spaces to avoid extremes of use (ie a very loud rock band practising in a music practice room during a critical recording in the studio).

As discussed in section 2.4.2, a finishes zone (typically 200mm) should also be allowed for in addition to the above constructions.

#### 4.1.7 Academic Exam Space (Room 4.201)

The current acoustic design of this space should be suitable for typical academic activities, however, it is understood that it could also be used for occasional ensemble rehearsal. Since the design of this space employs standard constructions (eg a single fixed floor slab, single walls etc) it is likely that the high sound levels produced during rehearsals will be clearly audible and disturbing to the adjacent spaces (eg English, History, Geography etc). There is also a potential issue with noise breakout from this space affecting external noise sensitive areas (eg dwellings etc). These issues require further consideration to determine the feasibility of using this space as an ensemble rehearsal room.

#### 4.1.8 Audition, Warmup, Soloist Rooms (9.062, 9.063 and 9.064)

Further discussions are required with the Client to determine their aspirations regarding these spaces. The current proposals show single doors in their main separating walls, which will significantly limit the sound reduction between these spaces. Therefore, with the current design it may not be possible to use these rooms simultaneously, ie use Room 9.064 for warm-up during an audition in 9.063. Also there are a number of noisy areas directly adjacent to these spaces (eg plantroom, substation, lift etc) which require further consideration.

#### 4.1.9 Floor Constructions

It is understood that the typical floor construction is likely to be a 300mm dense concrete flat slab. This should be adequate for the non critical spaces, and would also form a suitable base construction for the critical spaces.

A lighter-weight concrete floor slab has been proposed for most areas of the Academic School, which generally has lower sound insulation requirements. The proposed slab should be suitable providing that it achieves a minimum overall mass of around 380kg/$m^2$ (ie minimum slab thickness of 90mm at 2400kg/$m^3$ and a 75mm screed at 2200kg/$m^3$). There are one or two acoustically critical spaces in the Academic School (eg main edit room, music practice rooms etc) and the slab will be increased to the 300mm thick flat slab locally to these areas.

The floor / ceiling to the concert hall will be a minimum of a 200mm dense slab (to the classrooms), a large cavity, with a 150mm dense slab to the ceiling/lid of the hall.

#### 4.1.10 Doors

Initial requirements for doors are as follows:

- Concert Hall and Recital Hall - Sound lobby entrances with a minimum of $R_w$ 35 acoustic doors. Acoustically absorbent finishes will also be required in these lobbies to enhance sound insulation.
- Concert Hall Stage - Acoustic doors ($R_w$ 35 – 40 dB) are likely to be required between the stage area of the concert hall and delivery area. Since these doors often need to be large (ie to allow large instruments, staging etc) they are a high cost item.
- Music Practice rooms – $R_w$ 35 acoustic doors to each music practice room. In some cases (ie rooms for particularly noisy instruments) two $R_w$ 35 acoustic doors will be required.
- Ensemble Practice Rooms – these are likely to require sound lobby entrances, as discussed in relation to the Concert Hall.
- Recording Studio Control Room, Performance Area and Edit Room – typically $R_w$ 40 acoustic doors.
- Academic Classrooms – these will require minimum $R_w$ 30 acoustic doors

### 4.2 Vibration Isolation

The site is located in relatively close proximity (eg 30 to 40m) to operational train and tram tracks. A potential concern is that vibration produced by the trains and trams would give rise to unacceptable noise levels within the main concert hall.

A preliminary vibration survey has been carried out at the site to determine typical train/tram vibration levels. However, due to the complex nature of the ground conditions, it has not been possible to gain accurate measurements of the likely vibration levels that the auditorium will be exposed to. Since this issue is key to the acoustic quality of the concert hall, it is proposed that a more detailed assessment be carried out to determine typical train/tram vibration levels in the area close to the foundations of the concert hall.

It was not possible to carry out this survey during Stage D, however, the decision was taken to develop the design on the assumption that train and tram vibration would cause unacceptable noise levels in the hall. Therefore the design of the hall has been developed to structurally isolate this space from the ground and the rest of the building, by mounting it on anti-vibration bearings (similar to the approach taken at the Bridgewater Hall).

Another significant advantage of this approach is that it should be able to achieve a very high degree of both airborne and structure-borne sound reduction from the rest of the building, which would give maximum flexibility in use of the hall and building as a whole.

A detailed vibration survey will be required early in the next design phase to inform the design and selection of the anti-vibration bearings, and generally consider typical noise levels in other areas of the building due to train / tram vibration.

### 4.3 Surface Finishes

The wall and floor constructions discussed above relate to sound insulation. In addition to these constructions, the internal surfaces of the acoustically critical spaces will require acoustic treatments to control their room acoustic (sound absorbing or diffusing treatments). The requirements could range from 200mm thick zones for treatments to some of the walls and ceilings of the most critical spaces (eg recording studios etc) to 50mm thick zones for less critical spaces such as music practice rooms.

Generally, acoustically absorbent finishes will be required in most other areas of the building. Typical examples are:

- Academic teaching rooms - these types of spaces are likely to require acoustically absorbent ceilings.
- Foyer, Bar areas– these types of spaces should have acoustically absorbent soffits to minimise reverberant noise levels and noise transfer within these areas, and to other areas of the building. This could be a perforated / slatted timber type of finish, backed with an acoustically absorbent material (eg tissue faced mineral fibre).
- Circulation areas should have an acoustically absorbent soffit to minimise occupational noise levels, and minimise noise transfer into adjacent spaces.

Most spaces would benefit from a carpeted floor finish, as this can provide useful acoustic absorption to the space and also minimise impact noise transfer (ie footfall) to spaces below.

Appendix A

# Acoustic Terminology

# A1 Acoustic Terminology

## A1.1 CLARITY INDEX ($C_{80}$)

A technical index, expressed in dB, used to objectively evaluate orchestral or vocal (musical, not speech) clarity. Measured in Decibels, it is (10 log) the ratio of the total sound energy received in the first 80 ms following (and including) the direct sound energy to the sound energy received after 80 ms. The higher the value of $C_{80}$ the greater the expected subjective clarity.

## A1.2 DECIBEL (dB)

The ratio of sound pressures which we can hear is a ratio of $10^6$ (one million:one). For convenience, therefore, a logarithmic measurement scale is used. The resulting parameter is called the 'sound pressure level' ($L_p$) and the associated measurement unit is the decibel (dB). As the decibel is a logarithmic ratio, the laws of logarithmic addition and subtraction apply.

## A1.3 DEUTLICHKEIT / DISTINCTNESS ($D_{50}$)

A technical index, with no units, used to objectively evaluate speech intelligibility and vocal clarity. It is the fraction of the sound energy arriving within 50 ms of the direct sound. The higher the value of $D_{50}$ the greater the expected subjective clarity. $D_{50}$ is related to $C_{50}$ such that $C_{50} = 10 \log_{10}(D_{50}/(1- D_{50}))$.

## A1.4 dB(A)

The unit generally used for measuring environmental, traffic or industrial noise is the A-weighted sound pressure level in decibels, denoted dB(A). An A-weighting network can be built into a sound level measuring instrument such that sound levels in dB(A) can be read directly from a meter. The weighting is based on the frequency response of the human ear and has been found to correlate well with human subjective reactions to various sounds. It is worth noting that an increase or decrease of approximately 10 dB corresponds to a subjective doubling or halving of the loudness of a noise, and a change of 2 to 3 dB is subjectively barely perceptible.

## A1.5 EARLY DECAY TIME (EDT)

Similar to the reverberation time, but with the slope calculated over the first 10 dB of decay (and the time then multiplied by 6). Considered to correlate better than RT with the subjective impression of 'running' reverberance, ie reverberance during music.

## A1.6 EQUIVALENT CONTINUOUS SOUND LEVEL

Another index for assessment for overall noise exposure is the equivalent continuous sound level, $L_{eq}$. This is a notional steady level which would, over a given period of time, deliver the same sound energy as the actual time-varying sound over the same period. Hence fluctuating levels can be described in terms of a single figure level.

## A1.7 FREQUENCY

The rate of repetition of a sound wave. The subjective equivalent in music is pitch. The unit of frequency is the Hertz (Hz), which is identical to cycles per second. A thousand hertz is often denoted kHz, eg 2 kHz = 2000 Hz. Human hearing ranges approximately from 20 Hz to 20 kHz. For design purposes, the octave bands between 63 Hz to 8 kHz are generally used. The most commonly used frequency bands are octave bands, in which the mid frequency of each band is twice that of the band below it. For more detailed analysis, each octave band may be split into three one-third octave bands or in some cases, narrow frequency bands.

## A1.8 LATERAL ENERGY FRACTION (LEF of ELEF)

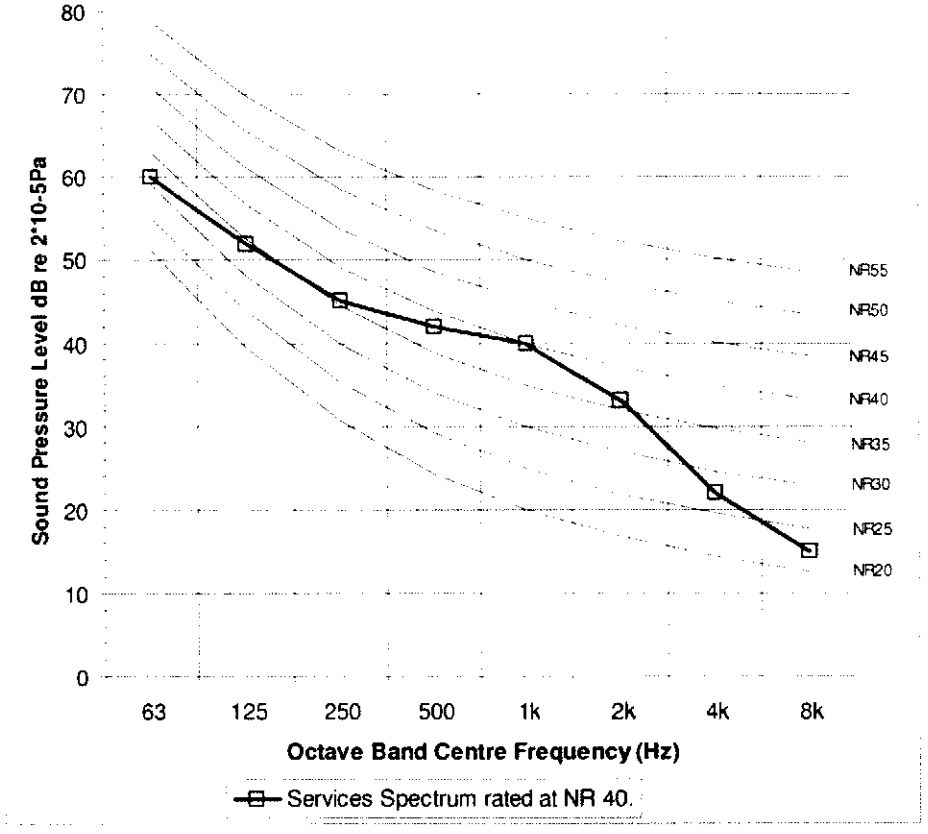
Sometimes called *Early* Lateral Energy Fraction, this index is considered to correlate with the subjective effect of source broadening. It is the fraction of the energy arriving at a receiver within 80 ms of the direct sound that comes from the side.

## A1.9 LOUDNESS (G)

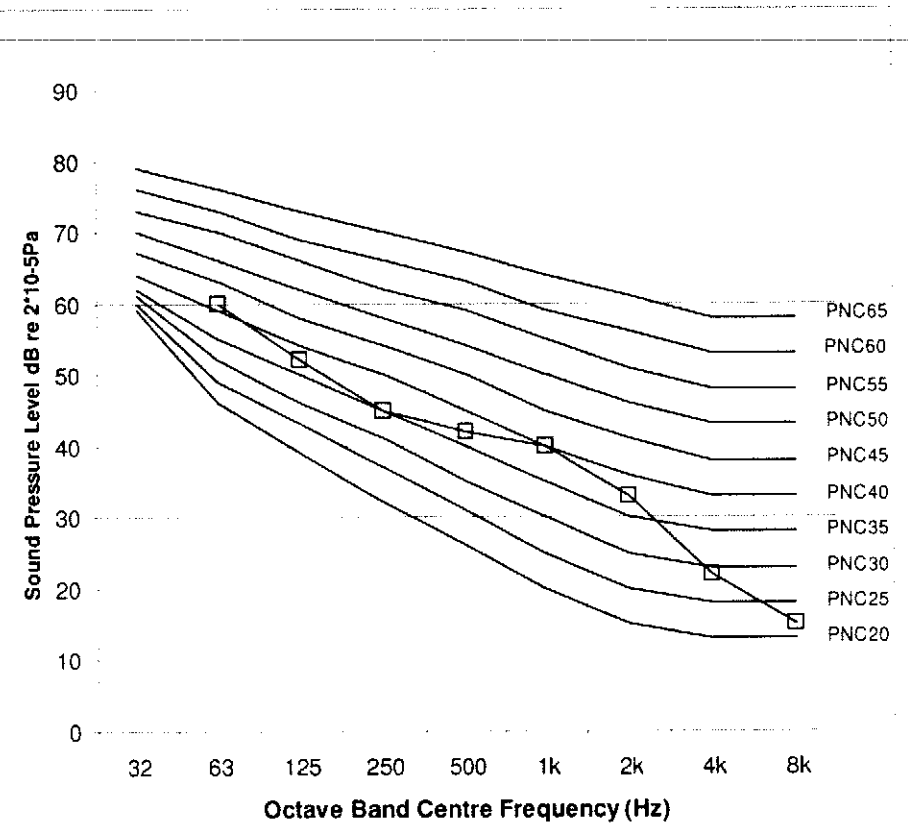
Loudness, or Strength, measured in decibels (dB), is defined as the sound pressure level produced by an onmidirectional source at the measurement point, relative to the level of the direct sound at 10 m from the same source.

## A1.10 NOISE RATING (NR) CURVES

Noise rating (NR) curves are a set of internationally-agreed octave band sound pressure level curves, based on the concept of equal loudness. The curves are commonly used to define building services noise limits. The NR value of a noise is obtained by plotting the octave band spectrum on the set of standard curves. The highest value curve which is reached by the spectrum is the NR value. Shown below is a plant noise spectrum that is equivalent to NR 40.



## A1.11 PREFERRED NOISE CRITERION (PNC) CURVES




A set of curves, similar in principle to NR curves, but considered to correlate better to subjective acceptability in very low noise areas such as music auditoria.

## A1.12 REVERBERATION TIME ($RT_{60}$)

The time, in seconds, taken for a sound within a space to decay by 60 dB after the sound source has stopped. An important indicator of the subjective acoustic within an auditorium.

## A1.13 SOUND LEVEL DIFFERENCE (D)

The sound insulation required between two spaces may be determined by the sound level difference needed between them. A single figure descriptor, the weighted sound level difference, $D_w$, is sometimes used (see BS EN ISO 717-1).

## A1.14 SOUND POWER

The sound power level ($L_w$) of a source is a measure of the total acoustic power radiated by a source. The sound pressure level varies as a function of distance from a source. However, the sound power level is an intrinsic characteristic of a source (analogous to its volume or mass), which is not affected by the environment within which the source is located.

## A1.15 SOUND REDUCTION INDEX (R)

The sound reduction index (or transmission loss) of a building element is a measure of the loss of sound through the material, ie its attenuation properties. It is a property of the component, unlike the sound level difference which is affected by the common area between the rooms and the acoustic of the receiving room. The weighted sound reduction index, $R_w$, is a single figure description of sound reduction index which is defined in BS EN ISO 717-1: 1997. The $R_w$ is calculated from measurements in an acoustic laboratory. Sound insulation ratings derived from site (which are invariably lower than the laboratory figures) are referred to as the $R'_w$ ratings.

## A1.16 SPEECH TRANSMISSION INDEX (STI)

A technical index, predictable and measurable using specialised equipment, for assessing speech and vocal intelligibility.

## A1.17 STATISTICAL NOISE LEVELS

For levels of noise that vary widely with time, for example road traffic noise, it is necessary to employ an index which allows for this variation. The $L_{10}$, the level exceeded for ten per cent of the time period under consideration, has been adopted in this country for the assessment of road traffic noise. The $L_{90}$, the level exceeded for ninety per cent of the time, has been adopted to represent the background noise level. The $L_1$, the level exceeded for one per cent of the time, is representative of the maximum levels recorded during the sample period. A weighted statistical noise levels are denoted $L_{A10}$, $dBL_{A90}$ etc. The reference time period (T) is normally included, eg $dBL_{A10,\ 5min}$ or $dBL_{A90,\ 8hr}$.

## A1.18 STRUCTUREBORNE NOISE

The transmission of noise energy as vibration of building elements. The energy may then be re-radiated as airborne noise. Structureborne noise is controlled by structural discontinuities, ie expansion joints and floating floors.

## A1.19 SUPPORT FACTOR, dB (ST1)

The difference in decibels between two measurements of sound pressure level made on a stage or in a pit. Sound is measured at a receiver 1 m away from an omni-directional sound source. The support factor is the ratio of the energy received up to 10 milliseconds after the direct sound to the energy received 20 to 100 milliseconds after the direct sound.

Appendix B

# Preliminary Guidance on Noise Control for the Building Services Installation

# B1 Preliminary Guidance on Noise Control for the Building Services Installation

## B1.1 Introduction

Control of building services noise will be essential to the success of the proposed new Chetham's School of Music building. The following report gives general guidance on noise control for the building services installations associated with this building.

## B1.2 Criteria

Target noise criteria for various typical spaces within the building are given in section 2.5 above.

## B1.3 Plantroom and Plant Spaces

All Air Handling Units (AHUs), fans, pumps, and other rotating and reciprocating plant should be fitted with efficient anti-vibration mountings (AVMs).

Plant mounted on AVMs should be isolated by flexible connections from ducts, pipes and conduits.

Ideally, plantrooms should be located as far away as possible from noise sensitive spaces (eg concert hall, recital hall, recording studios, music practice rooms etc).

Ducts between the AHU and associated primary attenuator (where this is duct mounted) should be externally acoustically lagged. Ductwork lagging will be required in other situations, especially where crosstalk could be an issue (see section B3).

Ductwork and pipework in the plantroom / plant space, and ductwork and pipework in contact with structures bounding noise sensitive areas (eg studios, rehearsal rooms etc) will need to be supported on anti-vibration hangers.

Riser shafts to and from plantrooms should be sealed so that they do not become noise transmission paths to other parts of the building.

## B1.4 Attenuators

Primary attenuators should be fitted in the AHUs or in the ductwork before it leaves the plantroom. Acoustic ductwork lagging will be required as noted above.

Secondary attenuators will most likely also be required on systems serving noise sensitive spaces (eg studios, rehearsal rooms etc). Crosstalk attenuators will also be required in certain situations in order to maintain the sound insulation integrity of acoustic structures, if secondary attenuators do not fulfil this function. Please refer to Figure B1.

Acoustic lagging will be required to ductwork between secondary attenuators and the point of entry to a noise sensitive space (eg studio etc). Similar provision will be required to ductwork associated with crosstalk attenuators (if any).

It is particularly important that there is sufficient space between AHUs / fans and the noise sensitive area served to accommodate the required attenuation, and to allow space between duct fittings to minimise regenerated noise.

Outline indications of attenuator sizes are given in Figure B1.

## B1.5 Regenerated Noise

Noise in ventilation systems is generated by the flow of air past diffusers, grilles, dampers, sound attenuators, turning vanes and duct fittings, as well as by the fan. The noise level generated at each location in the system depends on the air velocity and the local geometry and fittings. The ventilation systems need to be effectively designed to minimise airflow regenerated noise as far as possible.

Guidelines for air velocities are given in Figure B1.

Grilles and terminals should be carefully selected having regard to their noise characteristics.

If at all possible balancing dampers should not be used on systems serving acoustically critical spaces (eg studios, rehearsal rooms etc). However, if these are absolutely necessary they must only be located on the fan side of the secondary / crosstalk attenuator, and only be used to provide a slight balancing resistance.

## B1.6 Service Penetrations

Service penetrations (ducts, pipes and electrical services) through walls, floors, and ceilings must be sealed in such a way that the acoustic integrity of the structure is maintained and vibration transfer is eliminated. We will advise on penetration sealing methods in due course, however, the following table gives typical guidance on this:

| *Gap between service and structure (mm)* | *Sealing Details* |
|---|---|
| < 12 | Ram pack gap with mineral fibre and seal with non-hardening, silicone based sealant. |
| 12 – 20 | A close fitting cover plate comprising 12.5 mm gypsum plasterboard, or building board of similar surface mass, shall be bedded in mastic and fitted round the duct on both sides. The joint between cover plate and duct shall be sealed with a non-hardening silicone based sealant. |
| 20 – 50 | As above but with two layers of 12.5 mm plasterboard. |
| 50 – 100 | As above but with three layers of 12.5 mm plasterboard. |

**TABLE B1:** Guidelines for sealing penetrations

This is of critical importance at the plantroom penetrations and penetrations to studios, control rooms, music practice rooms etc, and other areas where a high level of sound insulation is required.

# B2 Routing of Services in or near Acoustically Sensitive Spaces

The routing of building services should be considered carefully by the design team early in the design. Services serving acoustically sensitive spaces must not be routed through noisy spaces or through other acoustically sensitive spaces. Services serving (only) other areas must not be routed through acoustically sensitive spaces. Noise can enter a duct or pipe in one space and be transmitted down the duct or pipe to another. Pipework should not be routed through acoustically critical spaces (eg sound studios etc).

Rainwater pipes transmit noise from outside and radiate flow noise in storms. They should be routed outside acoustically sensitive spaces, and should not be attached to the structure of acoustically sensitive spaces. Similar care must be taken in routing of drainage pipes from showers, washbasins and toilets.

Services passing into floating structures (eg studios etc) must not bridge the inner 'floating' room to the external building structure, and so will require flexible connections and other vibration isolation measures.

## B3 Crosstalk Attenuation

Control of 'crosstalk' (noise from one room entering a duct and being transmitted through the duct to another room), will be needed between spaces that require acoustic separation but are served by a common air system, and also where ductwork passes through high performance structures (eg auditorium walls etc). In many cases attenuators and areas of external acoustic lagging will be required (as discussed in section B1.4). Ducts serving adjacent acoustically sensitive rooms should be routed via the circulation spaces and not directly room-to-room, to reduce the requirements for crosstalk attenuation.

## B4 Special Precautions for Services Entering Box-in-Box Spaces

Ensure that all services entering isolated, box-in-box structures incorporate flexible elements as they cross the isolation joint. In the case of ductwork, this will be a flexible element. For conduit, a flexible section should be used; trunking should have a physical gap in it.

## B5 External Noise

Environmental attenuators, and possibly other means (such as acoustic louvres) will be required to control noise emanating from the plantrooms, air intake and discharge points or from externally mounted plant.

## B6 Electrical

Mains transformers, dimmer racks and voltage regulators may have to be mounted on proprietary rubber pads if these items are in close proximity to noise sensitive areas.

It may be necessary to use surface mounted light fittings in acoustically critical spaces (eg recessed fittings could compromise the sound insulation of their ceilings etc). Also, light fittings in these critical spaces should be selected to be silent in operation.

## B7 Lift Installation

The lift installations need to be carefully considered / designed with regard to any nearby noise sensitive spaces. Lift machinery and associated equipment should be vibration isolated.

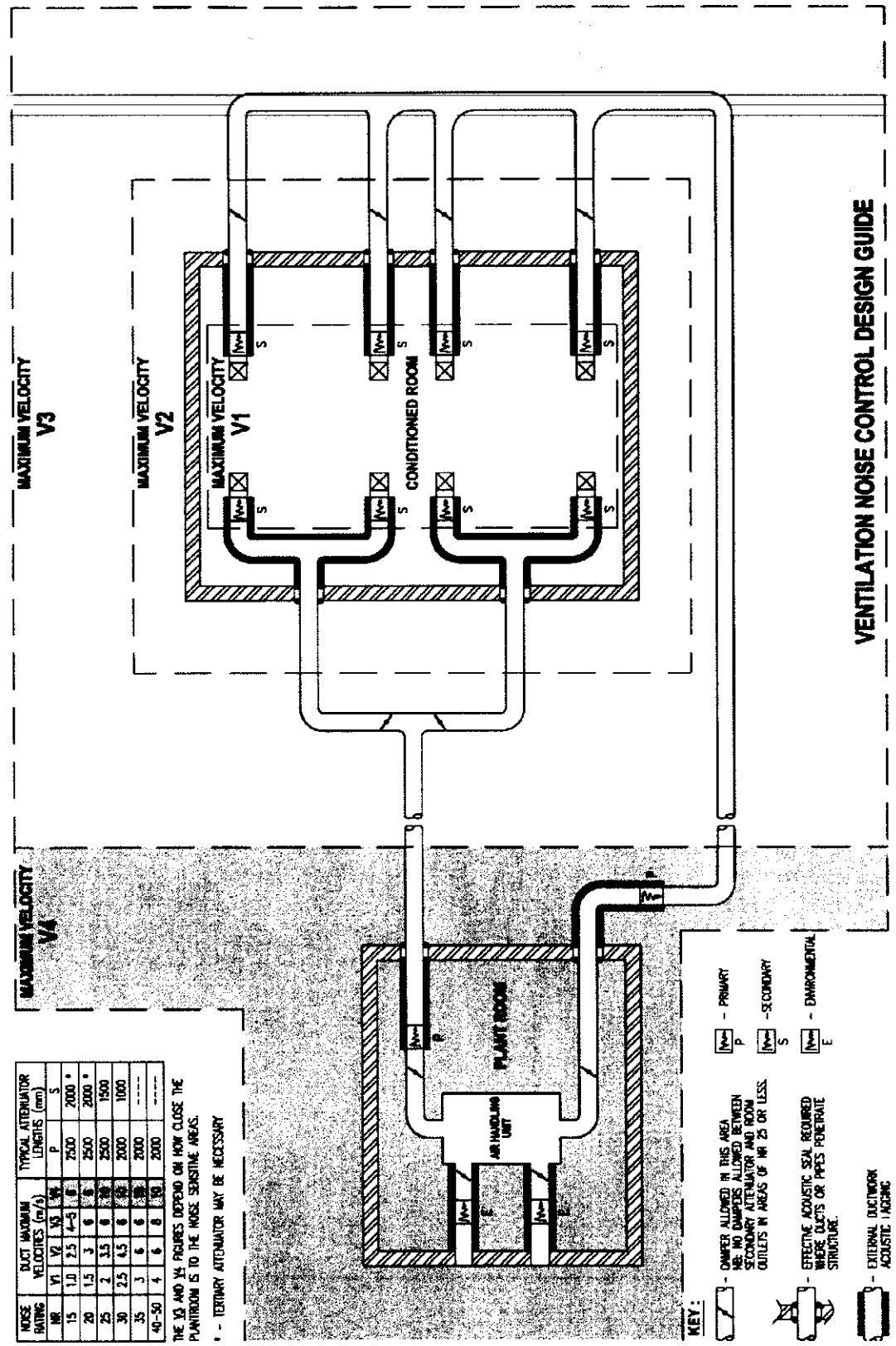



**FIGURE B1** –Guidelines for attenuators (location and typical sizes) and duct velocities

Appendix C

# Noise Survey

# C1 Survey Details

To establish the quietest time of day and night a fixed monitor was installed at the rear of the existing library of the School of Music in the Music Library Room. This location was chosen to be representative of the background noise level at the closest noise sensitive receiver to the proposed new extension, that being the existing girls dormitory.

Evening rush hour noise level measurements were taken at four locations representative of the facades of the proposed new extension.

The measurement locations are shown in Figure C1.

## C1.1 Survey Dates, Times and Personnel

Attended measurements were undertaken between 17:00 and 20:00 on 2 October 2006. The measurements were taken by Jamie Hladky and Steven Swan of Arup Acoustics. A number of five and ten minute measurements were taken and logged.

The fixed unattended noise survey was undertaken between 10:00 on 6 December 2006 and 14:00 on 14 December 2006. Equipment was installed by Craig Reid and Steven Swan of Arup Acoustics. The meter was installed to record and log noise levels over contiguous five minute periods throughout the measurement time.

## C1.2 Measurement Equipment

Measurements were carried out using the equipment detailed in Table C1. The sound level meters and microphones are Type 1 conforming to BS EN 60804. The calibration of the sound level meters and microphones was checked using the calibrator before and after the survey, to confirm there was no significant drift in meter response at the calibrator frequency and level. This verification indicated there was no more than a 0.1dB variation between checks. The meters are annually calibrated and this calibration is traceable to international standards.

Measurements were made for octave band measurements from 63Hz to 8kHz.

| Equipment | Manufacturer | Type |
|---|---|---|
| Precision grade sound level meter | RION | NL32 |
| Calibrator | Bruel and Kjaer | 4231 |
| Precision grade sound level meter | Bruel and Kjaer | 2260 |
| Microphone | Bruel and Kjaer | 4188 & 4189 |

**Table C1: Measurement equipment**

## C1.3 Weather

The weather was mainly dry throughout the majority of the measurement period with only occasional light rain showers. Wind speeds are believed not to have exceeded 5m/s.

## C1.4 Noise Sources

Noise levels at attended monitoring locations were dominated by road traffic noise, in particular bus manoeuvres at nearby bus stops and traffic lights.

The noise climate was dominated by road traffic at the unattended monitor location with contribution during quieter traffic flow moments from fixed plant associated with the MEN Arena and Victoria Train Station and to a lesser extent plant from the existing School of Music.

## C1.5 Results

Figure C2 shows the noise level trend throughout the measurement period at the fixed monitor location.

Tables C2 to C5 give measured levels at the attended monitoring locations.

| *Meas. position* | *Start time (hh:mm)* | *End time (hh:mm)* | *Free-field sound pressure level (dB)* | | | |
|---|---|---|---|---|---|---|
| | | | $L_{AFmax,\ 5min}$ | $L_{A10,\ 5min}$ | $L_{A90,\ 5min}$ | $L_{Aeq,\ 5min}$ |
| 1 | 17:49 | 17:54 | 85 | 72 | 55 | 69 |
| 1 | 17:54 | 17:59 | 77 | 67 | 56 | 64 |
| 1 | 17:59 | 18:04 | 85 | 74 | 57 | 70 |
| 1 | 18:04 | 18:09 | 85 | 72 | 55 | 69 |
| 1 | 18:09 | 18:14 | 82 | 73 | 55 | 69 |
| 1 | 18:14 | 18:19 | 81 | 72 | 56 | 68 |
| 1 | 18:19 | 18:24 | 83 | 73 | 58 | 70 |
| 1 | 18:24 | 18:32 | 83 | 71 | 56 | 68 |
| 1 | 18:32 | 18:37 | 83 | 74 | 55 | 70 |
| 1 | 18:37 | 18:44 | 81 | 71 | 56 | 67 |
| 1 | 18:44 | 18:49 | 85 | 71 | 55 | 68 |
| 1 | 18:49 | 18:54 | 83 | 69 | 54 | 66 |
| 1 | 18:54 | 18:59 | 78 | 70 | 54 | 65 |

**TABLE C2:** Free field sound levels measured at Position 1, dBA

| *Meas. position* | *Start time (hh:mm)* | *End time (hh:mm)* | *Free-field sound pressure level (dB)* | | | |
|---|---|---|---|---|---|---|
| | | | $L_{AFmax,\ 5min}$ | $L_{A10,\ 5min}$ | $L_{A90,\ 5min}$ | $L_{Aeq,\ 5min/10min}$ |
| 2 | 17:39 | 17:45 | 91 | 76 | 60 | 73 |
| 2 | 17:45 | 17:51 | 86 | 74 | 58 | 71 |
| 2 | 18:22 | 18:27 | 84 | 72 | 57 | 68 |
| 2 | 18:28 | 18:34 | 90 | 73 | 55 | 72 |
| 2 | 19:05 | 19:15 | 89 | 70 | 56 | 68 |

**TABLE C3:** Free field sound levels measured at Position 2, dBA

| Meas. position | Start time (hh:mm) | End time (hh:mm) | Free-field sound pressure level (dB) | | | |
|---|---|---|---|---|---|---|
| | | | $L_{AFmax,\ 5min}$ | $L_{A10,\ 5min}$ | $L_{A90,\ 5min}$ | $L_{Aeq,\ 5min}$ |
| 3 | 17:55 | 18:00 | 68 | 59 | 52 | 57 |
| 3 | 18:01 | 18:06 | 70 | 62 | 52 | 59 |
| 3 | 18:40 | 18:46 | 73 | 61 | 51 | 58 |
| 3 | 18:46 | 18:51 | 72 | 62 | 53 | 59 |

**TABLE C4:** Free field sound levels measured at Position 3, dBA

| Meas. position | Start time (hh:mm) | End time (hh:mm) | Free-field sound pressure level (dB) | | | |
|---|---|---|---|---|---|---|
| | | | $L_{AFmax,\ 5min}$ | $L_{A10,\ 5min}$ | $L_{A90,\ 5min}$ | $L_{Aeq,\ 5min}$ |
| 4 | 18:09 | 18:14 | 86 | 73 | 59 | 71 |
| 4 | 18:15 | 18:20 | 91 | 76 | 60 | 72 |
| 4 | 18:53 | 18:58 | 80 | 71 | 57 | 68 |
| 4 | 18:58 | 19:03 | 89 | 73 | 57 | 70 |

**TABLE C5:** Free field sound levels measured at Position 4, dBA

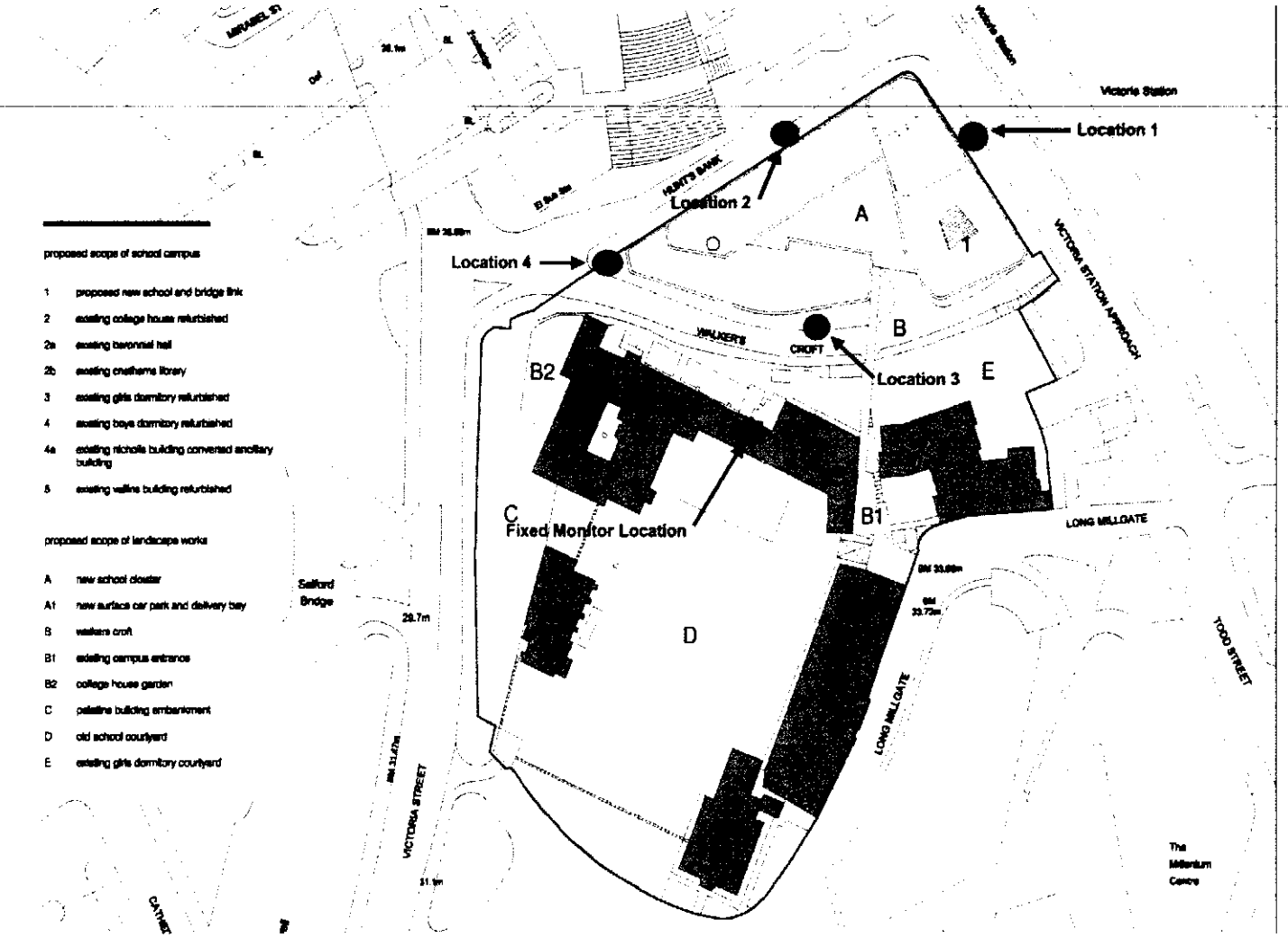



**FIGURE C1:** Site plan and measurement locations

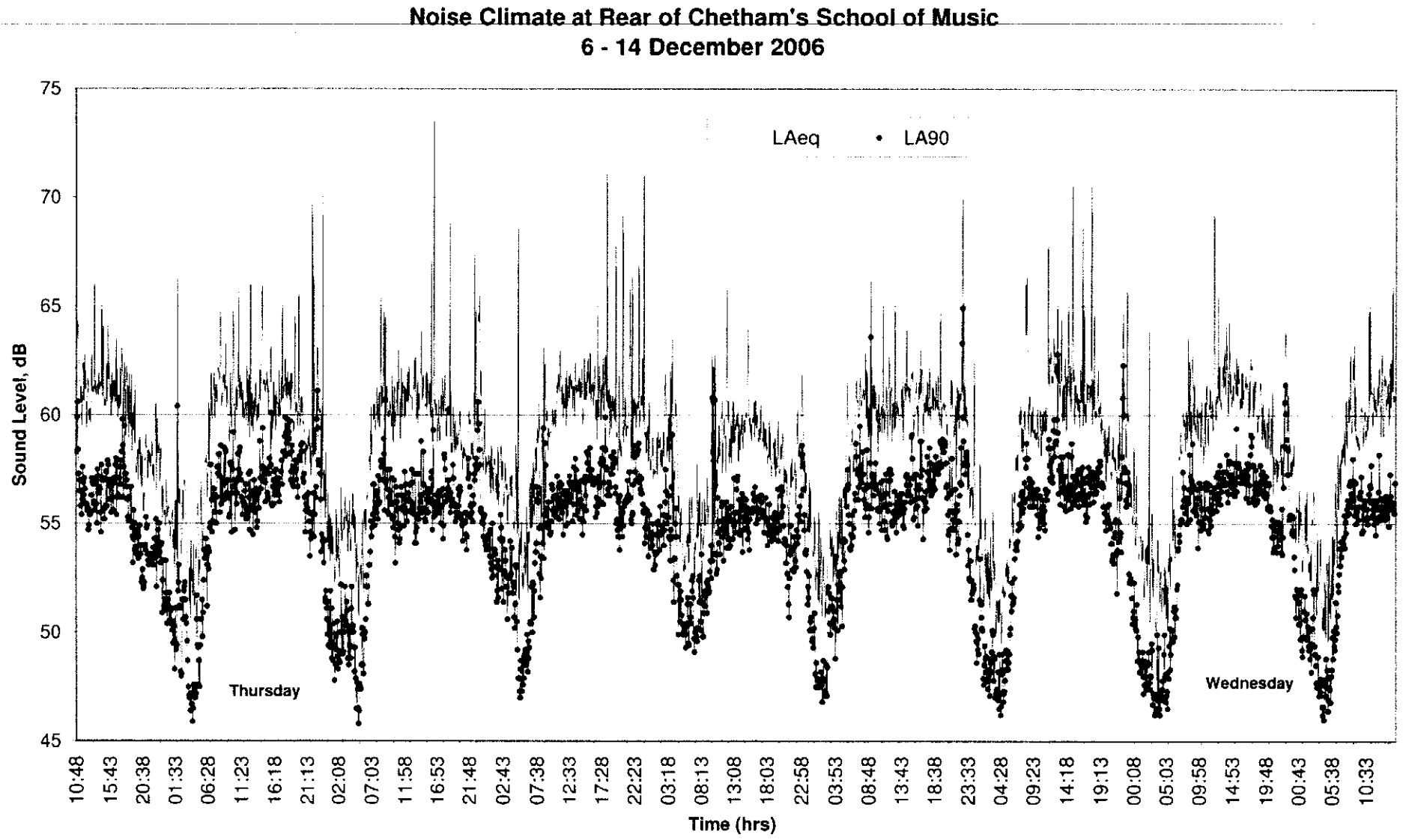



**FIGURE C2:** Measured noise levels at fixed monitor location, façade noise levels