



University of  
**Salford**  
MANCHESTER

# Living with helicopter noise : evaluating sound insulation techniques for domestic dwellings using real helicopters

Kerry, G, Waddington, DC and Lomax1, C

<http://dx.doi.org/10.1177/0143624411427376>

<b>Title</b>	Living with helicopter noise : evaluating sound insulation techniques for domestic dwellings using real helicopters
<b>Authors</b>	Kerry, G, Waddington, DC and Lomax1, C
<b>Type</b>	Article
<b>URL</b>	This version is available at: <a href="http://usir.salford.ac.uk/id/eprint/18582/">http://usir.salford.ac.uk/id/eprint/18582/</a>
<b>Published Date</b>	2013

USIR is a digital collection of the research output of the University of Salford. Where copyright permits, full text material held in the repository is made freely available online and can be read, downloaded and copied for non-commercial private study or research purposes. Please check the manuscript for any further copyright restrictions.

For more information, including our policy and submission procedure, please contact the Repository Team at: [usir@salford.ac.uk](mailto:usir@salford.ac.uk).

Title: Living with helicopter noise - evaluating sound insulation techniques  
for domestic dwellings using real helicopters

Running title: Living with Helicopter noise

Geoff Kerry BSc, FInstP, HonFIOA, CPhys, CEng

David Waddington BSc, MSc, PhD, MASA, MIOA<sup>a</sup>

Claire Lomax BEng, MIOA

Acoustics Research Centre

School of Computing, Science and Engineering

University of Salford

Salford M5 4WT

UK

---

<sup>a</sup> Responsible author: t: +(44) 161 295 4989/ e: d.c.waddington@salford.ac.uk

## **Abstract**

Specific remedial works designed to improve sound installation and reduce the noise level produced by helicopters inside dwellings are described. The theoretical problems and practical solutions to installing high performance acoustic insulation to a traditional property in the UK are presented. A novel application of ISO 140-5 is presented using real helicopters to measure sound insulation in-situ in the presence of multiple flanking transmission paths. Dedicated field trials to evaluate the performance of such acoustic double-glazing and associated modifications systems were performed and the precautions taken to minimise measurement uncertainties over the extended time period of the trials are detailed. The field trials involved the use of military training helicopters following selected flight paths around the property while noise level measurements were made internally and externally, before and after replacement of the existing single glazed windows and attenuated ventilation units were installed. The results show that after replacing the main windows with acoustic insulated glazing units, insulation levels of 40dB or above are achieved in most rooms. The results also illustrate the importance of effectively addressing ventilation when windows are replaced. It is concluded that despite complications due to sound flanking and regulatory ventilation, the use of acoustic double-glazing units and properly attenuated ventilation units can effectively reduce helicopter noise in suitable dwellings.

## **Practical application**

This paper provides an evaluation of ways in which the sound insulation of dwellings can be practically improved to reduce the impact on everyday living of noise from helicopter operations. It addresses concerns about the practical use of high performance acoustic insulated glazing units (IGUs) used in combination with acoustic through-the-wall ventilation. It also addresses the existence of multiple flanking sound paths. Sound insulation data from a field trial involving a conventional brick built house obtained before modification is compared in a controlled manner with that obtained after fitting acoustic IGUs and after introducing ventilation to comply with current Building Regulations.

## **1 Introduction**

A recent study carried out for the UK Department of Environment, Food and Rural Affairs (Defra, UK)<sup>1</sup> investigated the management of helicopter noise in the UK. The brief did not include a study into the amelioration of helicopter noise in dwellings but the report did highlight the fact that properties built near heliports and helicopter bases should be constructed with enhanced sound insulation properties. Traditional sound insulation schemes near airports have been aimed at reducing noise from large passenger jets or fast jets at military airfields, not necessarily helicopters. Many have evolved from the original Heathrow scheme based on adding secondary glazing inside window reveals and separate forced ventilation units. However, the need to minimise the use of fuel and power to heat homes has driven technology and resulted in the extensive use of insulated glazing units (IGUs) often referred to as thermal double glazing, in both the new build and replacement window market, and in the use of effective weather sealing/draught proofing to minimise air permeability and reduce energy loss and the personal discomfort caused by draughts.

The U.K. Building Regulations have also evolved over the years to maintain best practice. Sections controlling thermal insulation and ventilation have been introduced but scant regard has been paid to improving sound insulation. Standard IGUs are not particularly effective at sound reduction

but acoustic insulated glazing units, have now been developed using panes of different thicknesses, some laminated, which when mounted in high quality frames provide higher levels of sound insulation and some sound insulation schemes now incorporate versions of these units<sup>2,3</sup>. Relatively simple ventilation units have also been developed to fit unobtrusively into external walls to meet both the requirements of the Building Regulations and provide adequate sound insulation.

Acoustic consultants regularly advise that acoustic IGUs and attenuated ventilation units will provide a significant improvement in sound insulation and effectively reduce helicopter noise based on idealised laboratory measurements and experience with other sound sources. However there is very little evidence from practical examples quoted in the literature to support these recommendations, because of the many problems with applying a theoretical sound insulation value to real building for a sound source of this specific nature. It therefore seemed reasonable to investigate the use of acoustic IGUs and sound insulating ventilation units under practical conditions for such a purpose to ensure that a worthwhile improvement in sound insulation can be achieved specifically with a helicopter noise source. To this end a traditional brick built dwelling was made available near a military helicopter training airfield and with the assistance of the Local Authority, the Ministry of Defence, the landlord and

householder a programme of building works and evaluation tests was developed.

It was realised at an early stage that there would be considerable difficulties in carrying out a field trial of this nature not least because of the disruption to the householder. These difficulties became compounded when it was realised that the time scale would be much longer than a year due to the phasing of the building work, the availability of helicopters, the rural nature of the business run at the dwelling, and domestic programme of the householders. These problems were thought through with the parties involved and a programme set. The principle concern to the researchers was minimising uncertainties in the trial technique to ensure that each set of comparative measurements would be valid.

This paper details the methods adopted to minimise such uncertainties, the results obtained and the practical solutions to installing high performance acoustic insulation to a property whose construction is typical of many near airfields.

## **2 Methodology**

### **2.1 Aircraft, helicopters and sound insulation in dwellings**

Although many technological advances have been made in helicopter design, the scope for reducing noise at source from helicopters, especially military ones, is limited because engine efficiency and high power to weight ratios are essential parameters for their safe and effective operation. An alternative approach to control noise around many airfields is to insulate dwellings and other sensitive property most affected. The qualifying criteria have been established using noise contours defined principally for the amelioration of noise from jet aircraft and not helicopters.

Helicopter noise differs from that produced by jet aircraft in that although overall noise levels are generally lower, much of the acoustic energy lies in the low frequency part of the spectrum and is associated with the noise from the rotors. The combination of a slow or stationary noise source, different flight paths and high levels of low frequency noise could lead to the build up of noise within parts of the dwelling that can be exacerbated by room resonances, where the wavelengths of components of the noise coincides with room dimensions.

As a helicopter (or aircraft) flies by a dwelling, the resulting noise level experienced in a particular room depends upon a number of factors



including the aircraft flight path, orientation, power setting etc. and the acoustic performance of the building. The noise level is determined by the sound insulation provided by the individual building components that make up the dwelling as a whole, as well as the acoustic condition of the room itself. The latter depends upon the room dimensions and the furnishings and fittings; the former upon the way in which the dwelling has been constructed and the materials used. Each component (wall, roof, window etc) has an inherent sound insulation and the internal noise level will depend upon how much sound passes through each element. The amount of sound entering a particular room may also be dependent upon the size of openings (e.g. chimneys, ventilation bricks and gaps under doors) as well the amount of sound entering via paths through other parts of the dwelling, such as cellars and roof voids, and this can also include structure borne sound travelling directly through walls and floors.

Figure 1 illustrates a number of routes by which sound can enter a dwelling. In a conventional UK style brick built house, the walls and substantial roofs usually provide effective sound insulation but single glazed windows, lightweight or badly fitting doors, roof spaces without internal sound absorption (or constructed from lightweight timber/felted sections) and ventilation bricks and conventional chimneys can significantly reduce its effectiveness resulting in intrusive levels of noise in habitable rooms.

## **2.2 The test property**

The property comprises an “L” shaped two storey brick dwelling rendered in concrete with “mock” half-timber finish. The rear, kitchen door leads to a conservatory built into the “L” of the plan. Of relevance to the study is that the roof is of conventional tile and extends down over the bedrooms so that the top ½ metre of the bedroom sidewalls are formed by the ceiling/roof structure. The ceiling void has 75mm of glass fibre laid over the purlins. The main bedroom window is set in the gable end of the roof covering the short L and there is a hip roof over the second bedroom with a window set in its gable. There are no windows to the rear of the property apart from those in the conservatory but there is an extractor vented through the rear wall from the kitchen. There are air vents that lead directly into the front bedrooms below eaves level. The front entrance is in the centre of the façade with a clear view, facing the airfield. The door is a single half glazed timber door which leads directly into a vestibule with the lounge and dining room doors to left and right and the stairs immediately ahead. At the rear, the kitchen has a window overlooking the side of the house and two small windows looking directly into a plastic roofed ground floor extension (conservatory) built into the “L” of the plan. Rear access is through this conservatory. The lounge and dining room both have fireplaces but no

ventilators and the former has two bay windows. All doors are single timber plank farmhouse style.

Before the modification works were carried out, windows in the cottage on the front façade and the side lounge window were all fitted with single glazed panels of either 3mm or 4mm glass with standard weather-stripping. The kitchen side window and the rear bedroom window were fitted with double glazed units set in wooden frames with direct flow trickle ventilators set in the bottom of each frame. The double glazed panes were 4mm-6mm-4mm narrow airspace thermal units.

### **2.3 Selection of sound insulation components – windows.**

To obtain a satisfactory acoustic performance using either acoustic insulated glazing units or secondary glazing it is necessary to ensure that the window frames and the opening lights are well sealed and therefore it can be expected that the air permeability of such windows will be low. However since the introduction of the first noise insulation schemes around airfields<sup>5,6</sup> site tests<sup>5</sup> and comments obtained from users have indicated that this is not necessarily the case with secondary glazing.

Noise insulation grants schemes introduced in recent years at civilian airports<sup>2,3</sup> have favoured the use of acoustic double glazing and in particular

the use of 6-12-10.4PVB<sup>a</sup> laminate units (or 6.4PVB-12-10; - it does not matter which element has the laminate within) which has been shown to provide good insulation across a wide range of frequencies. Acoustic IGUs also bring the same advantages as traditional single glazing regarding access for cleaning inner surfaces, for quick and ready access to opening lights, for access to and use of any window sill area and for general internal room aesthetics<sup>4</sup>. Alternative units based on softer PMMA<sup>b</sup> laminates with the same glass thickness can provide higher levels of insulation but at a higher cost. Basic laboratory test data for the glazing systems are given in Table 1.

**Table 1: Laboratory test data for example glazing systems**

<b>Glazing type (thickness – mm)</b>	<b>Average SRI dB</b>	<b>Rw dB</b>
4 (single)	28	31
4-12-4 (conv. double)	29	31
4(100)4 (wide airspace)	42	44
6(200)10 (wide airspace)	47	49
10(12)6.4(PVB laminate)	36	40
10.8(16)6 (PMMA laminate)	41	41
16.8(16)16.8(PMMA laminate)	41	48

---

<sup>a</sup> PVB – Polyvinyl butyral laminate

<sup>b</sup> PMMA – Polymethyl methacrylate laminate

It can be seen that high performance acoustic IGUs can match the insulation provided by more conventional wide airspace double glazing. But this is at a financial cost. More practically there is significant improvement to be gained over either a single 4mm pane or a 4-12-4 conventional IGU by using the more modest 10-12-6.4 PVB laminated unit.

It was therefore decided to investigate the use of acoustic IGUs at the property by replacing the windows with heavy duty uPVC frames with opening lights in a frame pattern similar to those they were replacing and fitted with acoustic double glazing units incorporating 6.4mm (PVB laminate) - 12mm air gap – 10mm glass sealed units (coded 6.4L-12-10 or 6L-12-10) and to evaluate the performance in-situ when exposed to real helicopter flyby noise.

#### **2.4 Selection of sound insulation components – ventilation units**

When considering the acoustic insulation of dwellings it is normally assumed that the windows form the weakest element of the building. For this to be true the wall in which they are mounted must have a much higher sound reduction index than the windows themselves. This is normally the case with the UK building stock where external walls are usually made of dense brickwork. However the overall insulation of the wall and windows

may be reduced by sound gaining entry through other routes such as through roof structures, doors and chimneys and ventilators.

At the time that the first noise insulation grant schemes were drawn up, air permeability in most dwellings was high and it was considered not necessary to make the fitting of ventilation units compulsory when secondary glazing was installed unless required by the Building Regulations e.g. to supply air to a combustion unit<sup>7</sup>. More recently, improvements in building technology have resulted in a decrease in air permeability in dwellings leading, for instance, to an increase in condensation. The current U.K. Building Regulations therefore make the inclusion of an adequate means of ventilation mandatory.

The current U.K. Building Regulations, Approved Document F<sup>7</sup> requires that habitable rooms, kitchens, bathrooms and utility and sanitary accommodation in domestic buildings are provided with both whole building (background) ventilation and purge (rapid) ventilation. In addition in rooms where most water vapour and pollutants are released such as kitchens, bathrooms, utility and sanitary accommodation (known as “wet” rooms), extract ventilation, which may be either continuous or intermittent, is required to minimise their spread to the rest of the building. Background ventilation can be provided by air bricks with “hit and miss” grills, trickle

ventilators or suitably designed opening windows normally located 1.7m above floor level but it is no longer acceptable to rely upon gaps under doors and ill fitting window frames.

The acoustic performance of small building components such as trickle ventilators can be determined in an acoustic transmission laboratory using a special technique detailed in BSEN ISO 140 part 10<sup>8</sup>. The results are presented as a sound reduction value known as the weighted element normalised level difference ( $D_{n,e,w}$ ) and may be used in comparative calculations of overall wall performance with weighted normalised level differences ( $D_{n,w}$ ) obtained on larger wall components such as windows. The  $D_{n,e,w}$  of trickle and other ventilators should be at least 40 dB and preferably above 45dB if they are not to reduce significantly the overall sound insulation of the wall in which they are placed. This assumes that the external wall is of a dense construction such as 225mm plastered brickwork and that the windows (of conventional size) have been replaced by high performance acoustic IGUs.

Several proprietary wall mounted fan units are available that were developed for the attenuation of traffic noise following the introduction of the U.K. Land Compensation Act<sup>9</sup>. The requirements of the current U.K. Building Regulations were met by two proprietary acoustic wall vents with

external acoustic cowls which provided 20000mm<sup>2</sup> for combustion and ventilation in the lounge and dining room. In all other rooms trickle ventilation of 8000mm<sup>2</sup> was provided by two proprietary acoustic wall vents with external acoustic cowls. In addition, the powered wall fan unit in the kitchen was replaced with an acoustically attenuated version, and a similar unit was fitted in the bathroom.

## **2.5 Measurement methodology**

### *2.5.1 Flying programme*

Where possible a dedicated helicopter was used, providing total control over the flying programme and minimising the duration of disturbance to both the occupants and the local population. The aircraft type selected, a Griffin, had been shown to produce the highest noise level of the two basic training types available and also had the broadest noise spectrum with high levels of low frequency noise components generated by the rotors. During phase 2 however, limited availability of helicopters resulted in a Squirrel aircraft being tasked with adapting its training programme to carry out the flybys

The helicopters were required to operate at low level at approximately 200ft agl., and to fly past but not directly over the property at a horizontal distance of between 30m and 50m, and to repeat the procedure as required to



complete the measurement programme. Measurements were taken both outside and inside two rooms simultaneously ensuring that small deviations in flight track, engine settings or even helicopter type had no bearing on the final. For each set of insulation measurements in a room, at least 6 flybys were completed.

### *2.5.2 Schedule & procedure for sound insulation measurements*

Measurements were made at the property:

1. Before modifications (original)
2. After fitting replacement windows incorporating 6.4L-12-10 IGUs in uPVC frames in all habitable rooms in the property. (Phase 1)
3. After temporary modifications to the front door (Phase 1A)
4. After the replacement of hit & miss ventilators with acoustic ventilation units and fitting silenced units in unventilated rooms, a replacement front door and IGUs to the kitchen/conservatory (Phase 2)

The basis of the procedure adopted is outlined in BS EN ISO 140-5<sup>10</sup>. This international standard provides several methods to determine the sound insulation of a façade, with a view to providing data which can be used in calculations for similar structures elsewhere or to enable comparisons to be made with insulation data obtained in the laboratory. However data generated in the field must always be applied to other situations with some

caution. This is primarily because there are a number of ways in which sound can enter a dwelling.

BS EN ISO 140-5<sup>10</sup> also provides in an addendum a ‘global’ method of determining the insulation of a façade in terms of the standardised sound exposure level difference ( $D_{E,2m,nT}$ ).<sup>a</sup>  $D_{E,2m,nT}$  is calculated by adjusting the sound exposure level difference  $D_{E,2m}$ , by a factor which relates the reverberation time of the internal room to a reference reverberation time of 0.5secs ( $T_0$ , a typical value for a furnished room in a dwelling).

$$D_{E,2m,nT} = L_{E1,2m} - L_{E2} + 10\text{Log}(T/T_0) \text{ dB}$$

Where:-

- $L_{E1,2m}$  is the sound exposure level of the event measured outside the façade, nominally at a distance of 2m
- $L_{E1}$  is the average sound exposure level measured simultaneously inside the selected room
- $T$  is the average reverberation time of that room.

---

<sup>a</sup> The sound exposure level ( $L_{AE}$ ) is derived from the equivalent continuous noise level of an event  $Leq(t)$  such as an aircraft flyby. The  $L_{AE}$  value contains the same amount of energy over a normalised one second period. In this report the  $Leq$  levels are used, not the  $L_{AE}$  levels; since both internal and external sound levels were recorded over the same time period the normalisation is not necessary.

This global method was derived for measurements using transient sources such as trains and aircraft, which could be assumed to be at some distance from the façade. It acknowledges that because facades are comprised of several elements and not flat, there will be systematic errors in the sound level measurement particularly at low frequencies. It is possible that larger sampling errors could be experienced with helicopters which, in this instance, flew quite close to the properties. Layout and circumstances at the house meant that the external microphone was normally located between 1m and 2m from the window glass, approximately in the centre of the relevant window.

### *2.5.3 Internal microphone positioning*

Microphones were placed simultaneously inside and outside selected rooms. Inside, microphone positions were selected to ensure a reasonable spatial average of the flyby level would be obtained and to minimise undue room mode effects. Four positions were defined in each room as shown in Figure 2, chosen initially by drawing an imaginary diagonal across the room and placing the microphone tripods approximately:

1. One metre along the outside wall away from the front window wall and just off the diagonal
2. Half way down the outside wall, just off the diagonal
3. Half way along the window wall and just off the diagonal

4. One metre from the rear wall and from the internal wall

The microphone was fixed vertically on the tripod at either 1.2 or 1.5m above the floor. Usually two positions were selected at each height and the microphone offset ensured that the microphone positions were not symmetrical.

Furniture was left in its normal position in the rooms and it was therefore necessary to adjust slightly the microphone locations in each room by no more than 300mm so that each microphone was at least 0.5m from any surface (wall, ceiling floor or furniture). A note was made of each position and the microphones replaced at that position for each subsequent session. Between trials there was little change in furniture layout with most items remaining at or close to the same location. To ensure consistency, during all measurements, all the internal doors and all windows were closed.

*2.5.4 External microphone positioning*

External microphones were tripod mounted and located at heights so that they were approximately opposite the centre of the window of the room being monitored at nominally 1m to 2m from the face. Locating the tripod base so that exactly the same microphone position could be guaranteed was not possible and since the effect of local reflections from the window and its surround was unknown a special mounting was manufactured that allowed

microphones to be placed at 0.5m, 1.0m and 2.0m from the respective windows to allow a simultaneous assessment to be made of the variation between the sound level ( $L_{eq}$  for the event) measured at these locations during a helicopter flyby event.

The results showed that between the three outside measurement positions at first floor level, for seventeen separate measurements, the largest standard deviation measured was 0.7dBA, although it was generally less than 0.3dBA. The largest difference between the average first floor level measurement and the average ground floor level for an individual flyby was -1.2dBA, with more general differences of less than -0.5dBA recorded.

The C-weighted measures showed greater variations, with a maximum standard deviation of 0.9dBC and a typical standard deviation of 0.5dBC or less. The maximum difference between average first and ground floor sound exposure levels was 3.6dBC with the majority varying between 0.5 and 2.5dBC. It was therefore concluded that the positioning of the external microphone was not critical, even for low frequencies, although the larger difference between first and ground floor values, especially for C-weighted levels, warranted the separate determinations for ground and first floor insulation measurements.

### *2.5.5 Acoustical measurements and equipment*

Both inside and outside measurements were made using 01dB MCE212 ½ inch microphones fitted directly to PRE-12H preamplifiers. The signals were recorded on three 2-channel 01dB Symphonie type 1 analysers; one for the pair of outside microphones and the other two for the four inside microphones, as short Leq elements continuously over each trial. The microphones were fitted with windshields. Each measurement chain met the BS EN 60804:2001<sup>11</sup> type 1 specification. The measurement systems had all been verified using the British Standard BS7580: part 1:1997<sup>12</sup> procedure for type 1 sound level meters in a nationally accredited calibration laboratory. On site, the calibration of each measurement chain was verified with a 01dB calibrator, before and after each measurement session.

### *2.5.6 Post trial analysis*

For each recorded flyby, the time the helicopter was in close proximity to the dwelling was taken from the time history, and defined as the time the noise level was within 10dB of the maximum level as measured on the external microphone. The time averaged one-third octave spectra were calculated for each microphone, internally and externally. The differences between the measured external and internal 1/3 octave spectrum measured at each microphone for each flyby was calculated, and the sound insulation

was then calculated as the average of these differences.<sup>a</sup> An example of a measured time history is shown in Figure 3.

*2.5.7 Determination of the single figure weighted standardised level difference  $D_{H,1m,nTw}$ \**

The measured sound insulation is the external noise level minus the internal noise level for each of the four internal microphones for each flyby. The external noise level is given by the Leq ( $L_{E1,1m}$ ) measured between 1 and 2 metres from the relevant window and the internal noise level ( $L_{E2}$ ) is the spaced averaged Leq measured over the four microphones in the room. Both levels were calculated from the short Leq rms level over 1 second taken over the same flyby period when the sound level was within 10dB of the maximum. The results are therefore representative of average levels taken with the source at a range of angles of incidence since the helicopter would

---

<sup>a</sup> This procedure was used to minimise the effect of background noise on the internal noise levels and the calculated sound insulation. Background noise generated by internal noise in the house and by instrumentation noise affected some data at low frequencies and particularly at high frequencies. The 1/3 octave data below 20Hz and above 5kHz have been eliminated from the data but some data at 4kHz and above may have been affected slightly. The measured insulations at these frequencies will, in practice, be slightly higher than those recorded. It should be noted that the trial flybys were flown especially to improve the signal to background noise ratio.

have moved some distance over the normal to the particular window being monitored during the time of the flyby.

The practical evaluation of external microphone position reported above showed that the positioning of the microphone between 0.5 and 2.0m in front of each window was not critical. The measured sound insulation is therefore effectively the same as the sound exposure level difference defined in BS EN ISO 140-5:1998<sup>10</sup>. In that standard, the level difference is defined as the difference between the outdoor sound exposure level 2m in front of the façade and the space averaged sound exposure level in the receiving room. (\* $D_{H,1m,nTw}$  - suffix 1m used as more representative of actual position of mic from window)

The weighted standardised level difference  $D_{H,1m,nTw}$  ( $D_{Hw}$ ) values have been calculated using the procedure for evaluating single figure insulation according to BS EN ISO 717-1:1997<sup>13</sup> Acoustics – Rating of Sound Insulation in buildings and of building elements, using the definition given above for the standardised level difference.



### 3 Results

#### 3.1 Sound insulation data

Examples of internal and external noise levels and spectra are given in Figure 3 and Figure 4. The analysis was carried out in 1/3 octave bands but to simplify the discussion the data have been reduced to octave bands and the resultant measured sound insulations plotted in Figure 5. A simple single value measure of the sound insulation is provided by the weighted standardised level difference  $D_{H,1m,nTw}$  in Table 2. This has been compiled using the basic 1/3 octave data. The single number quantity term  $D_{H,1m,nTw}$  is essentially the same as the term  $D_{E,1m,nTw}$  which is derived from the octave  $D_{E,1m,nT}$  values. The subscript  $H$  has been substituted for  $E$  to clarify that the source is a helicopter.

The results of Table 2 show that overall there was an improvement in weighted standardised level difference ( $D_{Hw}$ ) of 6-14dB. There were only slight differences in spectra at each of the internal microphone positions which indicated that no local internal sound leakage paths (e.g. through doors) were present, although it was possible to hear the helicopters through the un-silenced wall ventilators (air-bricks) in the two front bedrooms until after the Phase 2 modifications. Despite the unusually close flybys, some measurements inside the property were influenced by background noise

above 4kHz due to low signal-to-noise and high attenuations at these frequencies.

### **3.2 Effects of room reverberation time**

Since there were no significant changes in room layout or content over the duration of the trials, the room reverberation times (as a measure of the total room sound absorption) would be largely unchanged, and therefore direct comparisons can be made between the insulation measured during each phase. In addition, since measured room reverberation times lay between 0.35 and 0.54 seconds, i.e. close to 0.5 seconds, there would be little difference between the measured sound insulation (as measured by the Leq event difference) and the standardised level difference also defined in the BS EN ISO 140-5<sup>10</sup>.

**Table 2: Weighted Standardised level differences  $D_{H,1m,nTw}$  (dB)**

Location	Measured Sound Insulation, $D_{H,1m,nTw}$ (dB)				Change (re original) in dB	
	Original	Phase 1	Phase 1+	Phase 2	P1 (P1+)	P2
Back Bedroom	33	41		33	8	0
Front Bedroom (left)	31	41	41	43	10 (10)	12
Front Bedroom (right)	31	39		42	8	11
Dining Room	30	42	41	38	12(11)	8
Kitchen	30	36		37	6	7
Living Room	30	44		40	14	10

## 4 Discussion

### 4.1 Sound insulation

#### 4.1.1 *Comparison with laboratory measurements*

With the exception of the kitchen and front right bedroom all rooms achieved a  $D_{Hw}$  of 40dB or above after Phase 1. The property can be considered as a substantial structure, being brick built with conventional roofs, and the sound insulation in each room would be governed primarily by the window(s) unless there were other flanking routes. The resulting overall insulation values are in line with expected values for acoustic double-glazing chosen (laboratory measured  $R_w = 41\text{dB}$ ). In practice it is generally found that the sound source is normally incident on the glazing over a restricted range of angles resulting in a slightly higher overall value than measured in the laboratory. However, this potential increase in insulation is usually countered by the shortcomings of the building construction (i.e. flanking paths), for example through unattenuated ventilation and chimneys.

#### 4.1.2 *Evaluation of acoustic performance of vents*

Sound insulation changes similar to those seen in the other bedrooms were observed in the rear bedroom when the acoustic double glazing was fitted.  $D_{Hw}$  increased from 33dB to 41dB. However this reduced to 33dB following the fitting of the silenced ventilators. There is no obvious reason for this other than the fact that the main source of ventilation when the wooden framed thermal glazing was fitted was small through the frame trickle vents. The final arrangement had two through-the-wall silenced vents, which may have contributed some leakage; however the reduction was greater

than expected and cannot be explained without further investigation. The sound insulation versus frequency curve indicates a loss at mid frequencies, which may result from an inadequate or faulty attenuator arrangement in the ventilation unit.

The  $D_{Hw}$  obtained illustrate how important it is to deal effectively with ventilation, which is now compulsory under the UK Building Regulations when windows are changed. It may be necessary to compromise sound insulation performance a little to provide adequate ventilation rates especially if remedial work is to be minimised. The loss of insulation in the kitchen may be attributed to the ventilation added to meet the Building Regulation's requirement to provide adequate combustion air.

#### *4.1.3 Comments on Phase 1 results*

The low sound insulation value in the kitchen following Phase 1 was considered to be the result of sound passing through the two single glazed windows from the conservatory with a possible contribution through the un-silenced ventilation unit. The conservatory roof is made from thin plastic sheeting and therefore acoustically very weak and therefore the original two conservatory/kitchen windows were subsequently replaced with acoustic double-glazed units in uPVC frames. These works were carried out as part of the Phase 2 works at the same time as the attenuating units were fitted to all existing through wall ventilation, with additional attenuated ventilators, where necessary, to bring every room up to the U.K. Building Regulations.

#### *4.1.4 Comments on Phase 1+ results*

An additional test (Phase 1+) was carried out with the front door sealed with an extra layer of plasterboard. This was a half glazed timber framed door leading directly inside to a small open vestibule at the foot of the stairs. Single timber plank doors led to the lounge, dining room and from the top of the stairs, the bedrooms. Originally, there were no plans to upgrade the front door and throughout the trials all the internal doors were kept closed, effectively turning the vestibule and stairwell into a useful sound insulation buffer area. A separate test during Phase 1 indicated that simple improvements to the mass of the external door did not increase the insulation provided by this vestibule and since, for everyday household activity, the dining room and lounge doors are normally left ajar providing little or no additional insulation to that of the front door, which faces the airfield it was replaced with a more substantial uPVC door with a small double glazed window and fitted in a new uPVC frame before phase 2 tests.

#### *4.1.5 Comments on Phase 2 results*

Table 2 also shows the differences pre and post the Phase 2 modifications at the property. This work resulted in increases in insulation in the two front bedrooms and the kitchen. However there was a reduction in insulation in the back bedroom, dining room and the living room. This may be due to the fitting of the through wall attenuated ventilators, which were not present before in phase 1.

#### *4.1.6 Influence of the Loft space*

No action had been taken to improve the sound insulation of the loft space, although an early inspection indicated that at least 75mm of mineral wool thermal insulation was already installed. In many situations, with a slate roof and a loft with a substantial space over a plasterboard or lathe and plaster ceiling, this would provide a reasonable insulated barrier to sound. A potential weakness, in this dwelling, was that the edge of the roof/ceiling formed the top part of the outer bedroom walls with limited separation between tile and ceiling and limited room for absorptive material in that gap, potentially forming a weaker area of sound insulation. The insulation performance of roofs over bedrooms could be critical in controlling the overall sound insulation in upstairs rooms (or all rooms in bungalows) and fitting acoustic double glazing alone may not achieve the gains expected. Many noise insulation grant schemes around civilian airports require action to be taken to improve the insulation in loft spaces if and where necessary<sup>2,3</sup>.

#### **4.2 Internal noise levels in the property**

The sound insulation values reported above were calculated the recorded external and internal noise levels that were much higher than would normally be experienced at the property. This ensured that the calculated sound insulation values were more accurate and free from any extraneous background noise particularly from other internal noise sources (electrical appliances, pipes, movement etc) except at high and very low frequencies.

To get an indication of the noise level that would be experienced on a daily basis at the property, it is necessary to refer the sound insulation measurements to external noise levels that would occur during routine operations. This has been achieved by using recordings of noise from helicopters on routine operational training flights from the airfield that were made during the Phase 2 measurement session (i.e. flights unconnected with the trial) and subtracting the measured insulation values from this ‘routine’ flyby data. However, the internal noise levels following the phase 2 modifications are, in general, sufficiently low that rotary wing noise will often be masked by internal noise resulting from domestic activity within both dwellings.

Examples of the time histories of these operational flybys can be seen in Figure 3 alongside examples of the trial flybys. Generally the flyby levels generated outside a dwelling in the vicinity of an airfield or helicopter landing ground will be dependent on the type of aircraft, the type of manoeuvre and the track and distance to the dwelling and the relative amount of shielding that parts of the dwelling itself might provide. The data presented in this section should only be considered as an example of the noise levels that can be expected at this particular property when a particular runway is in use. The results are presented in Table 3 in terms of the A and C weighted equivalent continuous noise level ( $L_{eq}$ ) over the relevant noisiest part of the flyby and as spectra in Figure 6.



Table 3: Internal overall sound levels calculated from operational sample flybys

Location	A-weighted Leq over Duration of routine event, dBA					C-weighted Leq over duration of routine event, dBC					C-A Difference	
	External level	Internal level (after attenuation by measured sound insulation values)				External level	Internal level (after attenuation by measured sound insulation values)					
		Original	Phase 1	Phase 1+	Phase 2		Original	Phase 1	Phase 1+	Phase 2	Original	Final
<b>Back Bedroom</b>	67.9	38.5	31.7		36.4	77.9	55	51.0		55.0	16.5	18.6
<b>Front Left Bedroom</b>	62.4	30.8	22.5	22.7	20.8	71.9	48.7	44.9	44.1	43.2	17.9	22.4
<b>Front Right Bedroom</b>	60.4	29	24.7		24.5	71.4	44.9	45.2		45.7	15.9	21.2
<b>Dining Room</b>	60.5	29.2	19.9	20.2	21.5	74.2	50.7	45.3	44.5	42.9	21.5	21.4
<b>Kitchen</b>	67.2	39.2	34.4		32.6	80.8	51.8	51.9		48.8	12.6	16.2
<b>Living Room</b>	59.5	31.3	21.3		26.4	74.8	52.8	48.5		47.8	21.5	21.4

### 4.3 Overall internal noise environment

With the exception of the back bedroom and kitchen, post phase 2 the calculated A-weighted internal levels in each room are similar and would, by many standards, be considered as very low. The C-weighted results show a similar pattern. A C-A difference  $>5\text{dB}$  indicates the presence of low frequency energy in the noise spectrum that could audibly be more dominant. A difference of  $20\text{dB}$  or more indicates a situation likely to cause greater annoyance<sup>14</sup>. The C-A difference either remained essentially the same or increased slightly. Although it is generally considered that reducing internal noise levels overall will usually result in more tolerance of a noise event, in this case the high levels of low frequency noise from the helicopter, enhanced by the insulation properties of the dwelling may give rise to concern. However much would depend on masking from noise generated by other internal activities.

Before any insulation works were carried out, low frequency levels ( $<63\text{Hz}$ ) were below the threshold of audibility as described by BS EN ISO 389-7<sup>15</sup> in most instances. Mid frequency, the noise levels were  $10$  to  $20\text{dB}$  above threshold in rooms at the front of the house and up to  $25\text{dB}$  at the back. The kitchen and back bedroom had the most intrusive noise at mid frequencies both before and after modifications. In the rooms at the front of the house noise levels after phase 2 were  $8$  to  $14\text{dB}$  above the audibility threshold at

500Hz. Many normal household activities result in internal noise levels at this level, some much higher, and it is likely that during the day only the noisiest flybys would be noticed. At night internal background levels are usually low and probably more flybys would be noticeable.

## **5 Conclusions**

A series of successful trials have been completed to evaluate the field performance of acoustic double glazing systems and specific remedial works designed to improve sound insulation and reduce the noise level inside properties produced by helicopters. The adoption of a rigorous trials programme at the outset minimised measurement difficulties and potential measurement uncertainties.

Most rooms achieved a  $D_H$  of 40dB or above after replacing the main windows with acoustic IGUs. These resulting overall insulation values are in line with expectations of the attenuation provided by the acoustic IGU chosen (Laboratory  $R_w$  41dB) indicating that the insulation of the property was limited by the sound insulation of the main structural components of the building. The results indicate that the rooms not achieving a  $D_H$  of 40dB, namely the rear bedroom and kitchen, are most probably influenced by the incorrect installation of the attenuated ventilation units.

The variation in measured insulation obtained following the installation of additional ventilation works illustrated the importance of effectively addressing ventilation, which is now compulsory under the U.K. Building Regulations when windows are replaced. It may be necessary to compromise a small degree of sound insulation performance in order to provide adequate ventilation rates, especially if remedial work is to be kept to a minimum.

The trial results also indicate that the inherent insulation of the dwellings will further enhance the proportion of low frequency energy in the internal noise spectrum. Although internal levels are low, and in some rooms very low, the presence of dominant low frequency components may cause some concern, especially if room resonances occur. However, there was no obvious evidence of any room resonance phenomena during the trials.

The project has demonstrated that the use of acoustic double glazing (6.4L-12-10) units and properly attenuated ventilation units can provide a significant improvement in sound insulation in suitable dwellings resulting in lower internal noise levels and are effective at ameliorating helicopter noise. Theoretically the same should apply to noise generated by fixed wing aircraft. However it is recommended that further field trials are carried out to evaluate performance to such noise sources.

The project has also highlighted the difficulties in assessing the value of installing these high performance elements in a property. It is recommended that a complete survey is carried out at any property where the installation of similar items is being considered, so that any potentially weak elements such as sound flanking routes that might limit the sound insulation can be highlighted before the decision to proceed is taken.

Whilst this work reports findings from only one dwelling it is nevertheless a demonstration of what can be achieved. Improvement measures are real and have brought a significant improvement to the lives of the occupants. This means that others can go ahead with some confidence that the introduction of such schemes will be effective provided that they are executed properly and with due regard to individual building characteristics.

## **Acknowledgements**

The authors and the University of Salford wish to acknowledge the considerable help that has been provided over the extended period of the project by a number of agencies. In particular, the support provided by staff from the Ministry of Defence, the Royal Air Force and the Local Authority. We are also indebted to the tenants of the property and their landlords, and to those agencies responsible for planning and project supervision. Funding for the project was provided by the Ministry of Defence and the Local Authority.

## References

1. Research into the Improvement of the Management of Helicopter Noise, Kendrick P, Waddington D, Kerry G, 2008  
<http://archive.defra.gov.uk/environment/quality/noise/research/documents/nanr235-project-report.pdf> Last viewed 31/08/2011
2. Liverpool John Lennon Airport: Sound Insulation Grant Scheme 2009.
3. Robin Hood Airport, Doncaster Sheffield: Sound Insulation Grant Scheme 2007
4. The Housing Association Property Manual, Technical Note Number 1: September 1994, Avoidance of Condensation Nuisance in Habitable Rooms.
5. Statutory Instrument 1989 No. 247 The Heathrow Airport-London Noise Insulation Grants Scheme 1989
6. Statutory Instrument 1989 No.248 The Gatwick Airport-London Noise Insulation Grant scheme 1989
7. The Building Regulations 2000: Approved Document F, Ventilation; F1 Means of Ventilation (2006 edition)
8. BS EN ISO 2140 -10:1992 (ISO 140-10:1991), Acoustics – Measurement of sound insulation in buildings and of building elements - Part 10: Laboratory measurement of airborne sound insulation of small building elements.
9. The Land Compensation Act, 1973 (c26), HMSO

10. BS EN ISO 140-5 Acoustics – Measurement of sound insulation in buildings and of building elements – part 5: Field measurements of airborne sound insulation of façade elements and facades
11. BS EN 60804:2001 (IEC 60804:2000) Integrating-averaging sound level meters
12. BS 7580-1:1997. Specification for the verification of sound level meters. Part 1. Comprehensive procedure.
13. BS EN ISO 717-1:1997 Acoustics – Rating of Sound Insulation in buildings and of building elements.
14. A review of published works on low frequency noise and its effects, Leventhall G, Pelmear P, & Benton S. 2003  
<http://archive.defra.gov.uk/environment/quality/noise/research/lowfrequency/documents/lowfreqnoise.pdf> Last viewed 31/08/2011
15. BS EN ISO 389-7: 2005, Acoustics- Reference zero for the calibration of audiometric equipment – Part 7: Reference threshold for hearing under free-field and diffuse-field listening conditions.



## **List of Figures**

Figure 1: Illustration of sound transmission paths from a helicopter into a residence

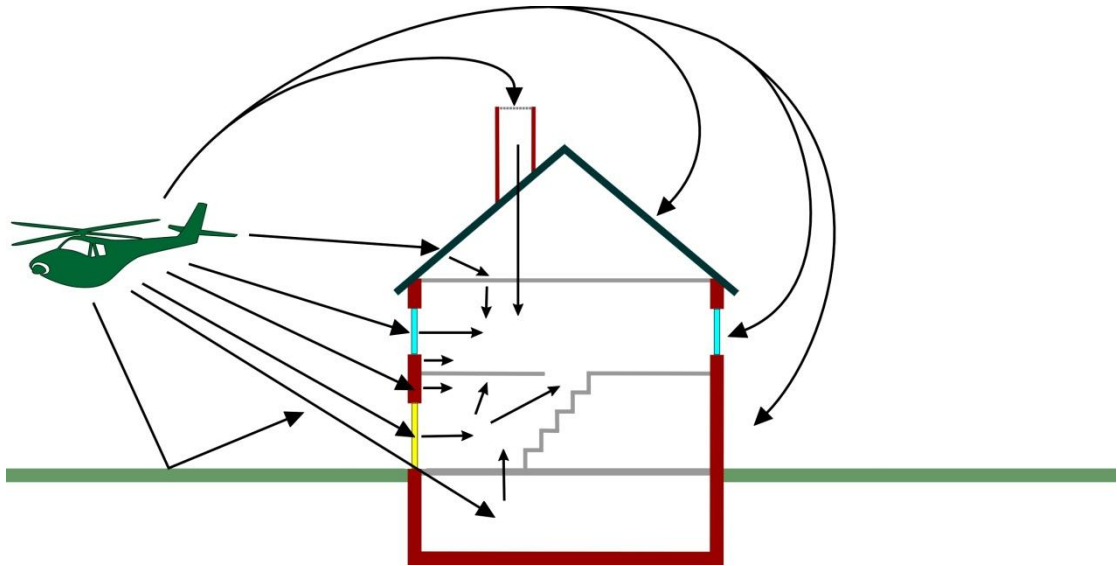
Figure 2 Typical microphone positions

Figure 3: Leq dBA level time histories measured inside and outside the front left bedroom. High level trial flyby used for insulation calculations: 11h24m08 to 11h24m14. Routine operational flyby: 11h16m36 to 11h16m52

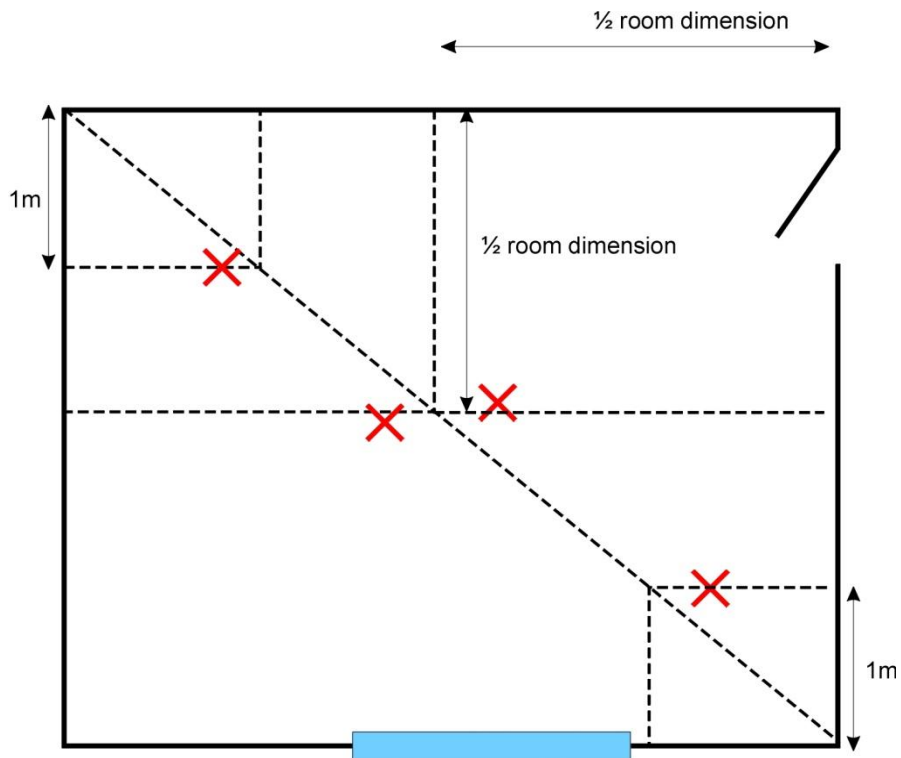
Figure 4: Internal (black) and external (blue) spectra for a typical flyby.

Figure 5: Sound insulation measured in each room

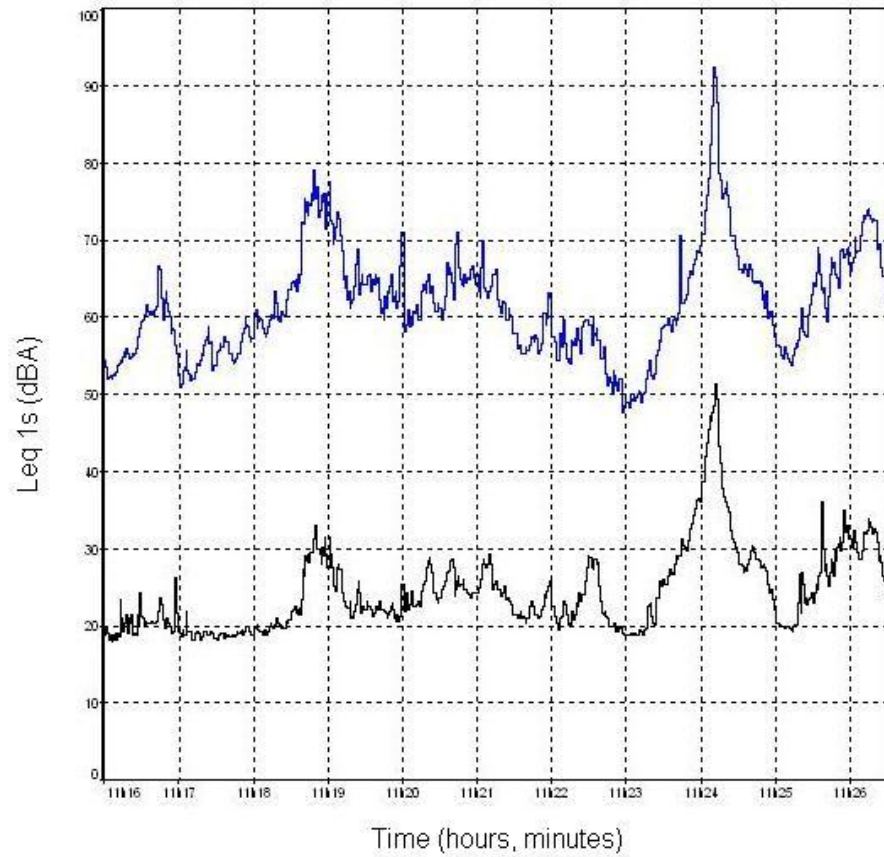
Figure 6: Internal noise level measured in each room



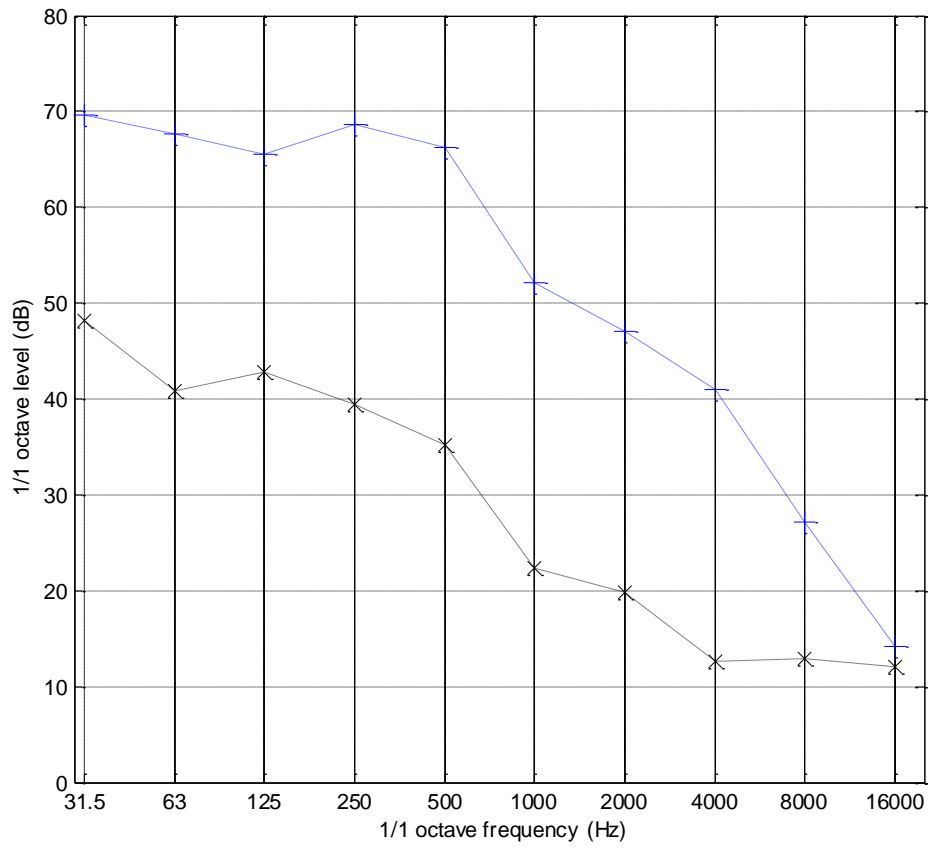
**Figure 1: Illustration of sound transmission paths from a helicopter into a residence**



**Figure 2 Typical microphone positions**



**Figure 3: Leq dBA level time histories measured inside and outside the front left bedroom. High level trial flyby used for insulation calculations: 11h24m08 to 11h24m14. Routine operational flyby: 11h16m36 to 11h16m52**



**Figure 4: Internal (black) and external (blue) spectra for a typical flyby.**

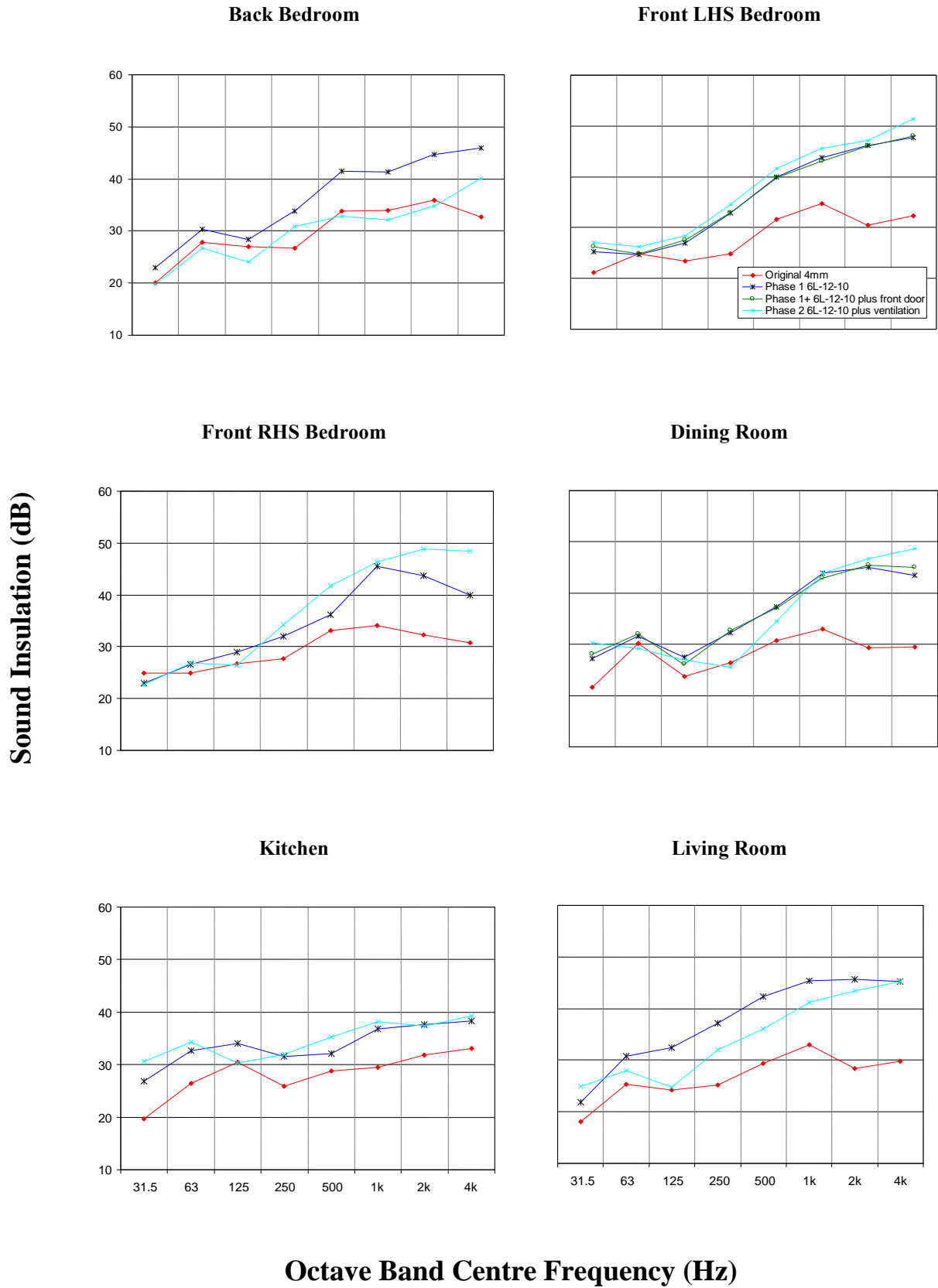


Figure 5: Sound insulation measured in each room

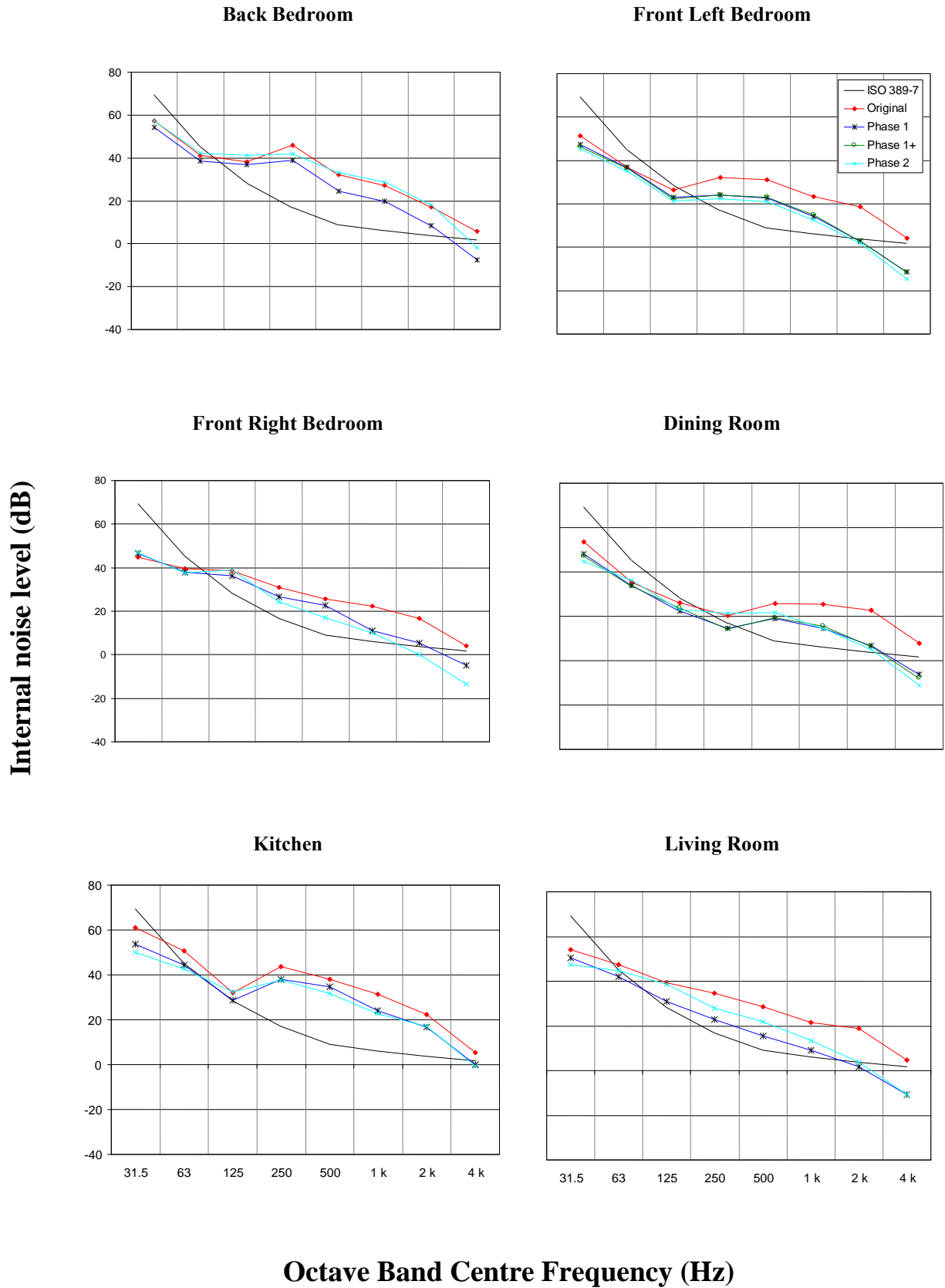


Figure 6: Internal noise level measured in each room