Notes on the acoustical design of animal holding rooms within medical research facilities

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ABSTRACT

The acoustical design of animal holding and behaviour rooms is particularly important to the function of medical research facilities. Achieving suitable internal conditions is crucial to the operation of animal houses and the research outcomes they support. State-of-the-art research literature remains inconclusive regarding objective (i.e. measureable) criteria, but demonstrates high risks associated with adverse noise and vibration environments in animal research laboratories. For animals subjected to adverse noise and vibration, these risks include significant impacts on reproduction and sensory development, behaviour, and even physical injury from startle responses. This paper reviews relevant work to date and measurements of existing facilities and activities. The discussion focuses on common design limitations, proposed criteria and general recommendations.

INTRODUCTION

The 'Animal House' is a common term given to animal holding and observation facilities to service the requirements of small animal-based research. Maintaining suitable internal conditions within the Animal House is crucial to the facility operations and the research outcomes they support.

The literature remains inconclusive regarding objective (i.e. measureable) criteria, but demonstrates substantial risks associated with adverse noise and vibration environments in animal research laboratories.

Faith & Miller (2007) noted that for animals subjected to excessive levels of noise and vibration, risks include

- modification of neuroendocrine and cardiovascular function and accelerated hearing loss,
- disturbance of natural sleep-wake cycles,
- disturbance of breeding / reproductive cycles,
- induction of seizures in susceptible strains,
- changes in reproduction and development,
- alteration of the toxicologic properties of certain agents and immune functions,
- induction of an array of behavioural and physiological changes, and
- physical injuries from startle reactions and sudden stimuli.

In other words, harsh environmental noise and vibration conditions can render animal research facilities ineffective through a variety of mechanisms, from animal harm to impacting actual research observations and findings. Where animal houses are in close proximity to a number of significant noise and vibration sources both external and internal, particularly in facilities integral to major hospitals, it is important to establish appropriate design criteria early in the design and ongoing operation of the facility.

This paper provides a short review of existing published guidelines and other literature on the subject, and discusses likely design decisions surrounding acoustic controls.

Data obtained from an existing animal research facility has also been provided to provide additional context to recommendations.

CODES AND GUIDELINES

Table 1 of AS/NZS 2107:2000 under Health Buildings - Laboratories recommends targets of L_{Aeq} 45 dB (Satisfactory) and L_{Aeq} 50dB (Maximum). It is noted that these values were established on the basis of human occupation, and do not address characteristics of perhaps more relevance to the factors raised by Faith & Miller, such as loud short term events and ultrasonics.

A design reverberation time of 0.4 to 0.7 seconds is also listed for this category of occupancy. However the specification of any specific sound absorptive interior finishes will need to stand up to operational and bacterial control requirements, including air tightness.

Neither the UK technical guideline HTM 08-01 (United Kingdom Department of Health 2008) which has some recognition within Australia in regard to the design of hospitals, or its 2012 successor (UK United Kingdom Department of Health 2012), have criteria specific to the design of animal research facilities. However, there exist longstanding specific UK guidelines on the housing and care of animals (HMSO 1995).

These 1995 guidelines state that "loud, unexpected and unfamiliar sounds including ultrasound" can disrupt breeding programmes and cause disturbances to behaviour. However, these guidelines also note that constant background sound levels are not indicated to be a health risk to animals provided those levels are "not too loud".

The Animal Welfare Branch of the NSW Department of Primary Industries (2003) has published several guidelines specific to various animals that may be in animal house facilities. There are common themes in regards to the noise and vibration environment, being that:

- Human activity and laboratory equipment are important sources of sounds which may have substantial, negative impact; and

- Vibration tends to have similar effects on laboratory animals as exposure to noise. Whole body vibration at low frequencies below the range of effective hearing can have similar effects as noise stress to various regions of the brain.

Section 3.3.4 of the Victorian Government Department of Primary Industries Code of Practice for the Housing and Care of Laboratory Mice, Rats, Guinea Pigs and Rabbits (State Government of Victoria 2012) notes the importance of establishing suitable noise and vibration control, particularly against sharp, short term, unfamiliar noise levels.

This section provides several recommendations including that
- background noise, including ultrasound, "should be kept below 50dB" and should be free of distinct tones;
- Short exposure noise to be less than 85dB; and
- Low level background noise may be suggested for guinea pigs and rabbits to minimise the risk of injury through startle reactions.

It is noted that Section 3.3.4 does not clarify several important aspects for assessing the recommended background or short exposure noise level targets, such as frequency weightings (particularly if ultrasound is to be included), the measurement descriptor or objective definitions of low level noise.

This aligns somewhat with guidance from the United States National Institutes of Health (2008) which comments that research laboratories are generally rated to NC40 to NC45, based on rooms not being occupied and with all user equipment off. A maximum noise level of NC45 is also stated, not for animal comfort, but for "reasonable speech communication".

DISCUSSION OF DESIGN ASPECTS

General arrangement

Typically, the acoustically sensitive areas within the Animal house are usually referred to as behavioural, holding and procedure rooms. Behavioural rooms usually demand higher levels of acoustic control as they are specifically used for monitoring of animal responses to a given experiment.

The facility will usually have cage washing and make up areas on site, and these spaces are often viewed as the noisiest. This is not simply because of the scale of the cage washing machines typically used – cages are handled and dropped onto hard benches with less discipline than staff would ideally employ within holding or behavioural rooms.

Internal sound levels

Internal sound levels are typically defined in terms of a continuous (background) and a short term or transient maximum level. They are discussed separately in the following subsections.

It is important to start with the animal holding environment at its basic level – the cage. Responding to their immediate environment, the animals themselves are the key noise source, and the cage design itself is important to ensuring suitable amenity.

Generally, design will lean towards individual ventilated cages (IVC) which utilise built-in ventilation measures. We note that most commercially available systems are already developed to comply with acoustic requirements listed in the current codes of practice, the designer then requiring only a brief review of technical documentation and warranties from the supplier.

Cage design forms a relatively small part of the design process which will need to be fully integrated with the layout, furnishing and operation of each area in the Animal House (Faith and Miller 2007):

> "It becomes evident that minimizing the impact of sound and vibration requires thinking beyond the [individually ventilated cage (IVC) racks] to everything that is in the macro-environment of the animal room or that integrates with the room. Every piece of equipment in the room or external system that touches the room should be reviewed.
> …
> To create a truly quiet environment for animals, we must look beyond the rack to the construction of the room, other equipment in the room, and any penetration into the room such as HVAC or monitoring equipment. Nothing can be ignored."

For example, the cage holding rack construction is usually a decision between steel and engineered polymer. Steel cages lead to higher short term noise as units are moved onto and off shelves (particularly ultrasonic noise) but are considered more durable and maintainable.

Beyond the cage, typical noise sources within each animal house room include
- operation of equipment, husbandry, cleaning and maintenance procedures, including running water taps, adding food pellets or placing items on hard surfaces,
- building services and plant,
- vocalization and activity of animals, either without stimulation or in response to researcher activities,
- light fixtures and computer terminals – e.g. high frequency noise from electrical equipment, ballast lighting.
- personnel and equipment movement, and
- individual and group activities of visitors, staff and research themselves within adjacent laboratories and spaces.

Continuous noise levels

It is the experience of the author that designers invoking Australian codes of practice employ a continuous noise limit of L_{Aeq} 50dB and a services design target of NR40, without establishing specific ultrasound noise level targets.

Sound masking systems might be a consideration in terms of providing stability to ambient sound levels and minimise the risk of sudden noise stimuli.

Anecdotally, some animal house facilities typically have all doors open, with radios operating. Background music as 'masking noise' to reduce the influence of sudden noises in a facility is a method discussed by Faith & Miller (2007):

> There is evidence both in support of and against this practice. Intercom systems playing elevator music unquestionably dampen startle response to sudden noises, but there is also evidence that rodent hearing doesn't fully develop normally when subjected to constant white noise, which would argue against this approach. The negative impacts of auditory stress are not insignificant. For example, banging of cages in an animal room can cause a 100% to 200% increase in plasma corticosterone in rats, which persists for two to four hours. Exposure of pregnant rats to an 85 decibel (dB) to 90dB fire alarm bell results in alteration of immune function in the offspring.

Whilst the literature is inconclusive as to acceptability of music or radio, the potential negative effects of adverse noise and vibration are well established. It is feasible that these risks and effects are not fully understood by researchers (or accounted for in their research outcomes) when they use the radio or play background music.

Maximum noise levels

The literature clearly finds that the control of short term / transient noise levels is a key issue, both from a design and operation viewpoint. The acoustic design needs to consider both internal and external sources, with an understanding as to the frequency of each short term or transient noise level event.

Animal behaviour rooms involve monitoring of the animals in controlled environments and arguably carry additional sensitivity to short duration events.

Despite the following discussion in regards to ultrasonic noise, it is the experience of the author that historically, maximum noise level targets have been established using the L_{AmaxF} metric on the basis of consistency with other design targets and relative ease of measurement within the room. Refer to the below section 'Physical Survey' for an example of such measurements.

Furthermore, a target of L_{AmaxF} 65dB has been shown to be consistently below or equal to typical values of expected staff activities within holding rooms, for typical layout and furnishings.

Ultrasonic noise

Figure 1 presents typical frequency ranges of hearing for various animals as reproduced from Heffner and Heffner (2007). Noise criteria using the dB(A) unit descriptor is intended for the human hearing response (typically bounded to the range 20Hz to 20,000Hz). As the authors noted from this figure, Norway rats, mice and other typical laboratory animals have substantially higher sensitivity to high frequency sound than humans.

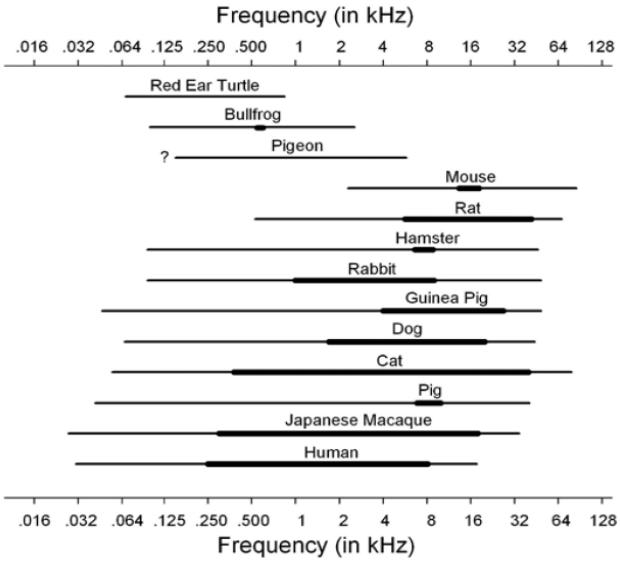

Figure 1. The hearing ranges of laboratory animals compared with those of humans. Thin lines indicate the range of frequencies that can be detected at 60 dB SPL; thick lines indicate the range that can be detected at 10 dB SPL. Reproduced from Heffner and Heffner (2007).

In the absence of firm research guidance, maximum design criteria for frequencies outside this range ('ultrasonic' and 'infrasonic') can be accounted for using the R-weighting (Voipio 1997, Björk *et al.* 2000).

There are few references to the R-weighting in Australia; however there exists various studies on the measured ultrasonic noise from typical activities within animal research facilities (Sales *et al.* 1988, Sales *et al.* 1999) particularly in terms of overall dB(R) values (Voipio *et al* 2006).

It is not beyond the capabilities of commercially available equipment to measure airborne noise levels in excess of 20kHz in order to determine dB(R) values.

Regardless, all practicable opportunities to reduce ultrasonic and infrasonic noise impacts should be considered by the design team. Simple yet effective materials for the control of ultrasonic radiation have high dampening properties and include rubber, low density polyethylene (LDPE) and polystyrene (PS) (Birke 1988, Sobotka *et al*. 2003).

Within holding and behaviour spaces, key noise sources include:

- high frequency ballast lighting – substitute with steady state / LED lighting or acoustically treat starters and ballasts;
- air or water spray hoses – procedures to relocate animals to other areas, or revised maintenance systems;
- tilt/focus elements of video cameras – procure remote motor / linkage type, recess into a screened wall or ceiling cavity and/or acoustically treat; and
- emergency warning / information speakers – select 'low frequency' (sub 400Hz) type speakers or substitute if possible for silent paging or visual alert systems.

Video displays, fan cooled computers, furniture, vacuums, and cage washers are seen as other sources of ultrasonic noise which has the potential to impart adverse health effects on laboratory animals (United States National Academy of Sciences 2004).

Vibration, infrasonic noise

Section 5-2 of US guidelines (NIH 2008) recommends vibration velocity limits of 100µm/s for animal house facilities, down to 50µm/s for animal behaviour and holding rooms, including footfall vibration at various defined speeds.

Within Australia, application of Curve 1 of ISO 2631 and in the latter case, Curve VC-A as defined in ASHRAE (2003) guidelines is considered reasonably consistent within the US guidelines.

Given the above it is clear that any powered laboratory equipment or other sources of vibration should not be located on the same benchtops or racks as the animal(s).

Vibration stability, the variation in vibration levels throughout an extended observable period, is considered important as it directly impacts on needs for a constant observation environment. However there remains little guidance as to what would be an acceptable level of instability on a daily or otherwise basis.

Reverberation times

Reverberation times are generally not required to be followed, as the occupancy beside the animals usually only one person, and occasional at that. Regardless, bacterial control requirements (for all surfaces to be impervious and hard wearing) would usually carry higher priority.

APPLICATION NOTES

The location and arrangement of sensitive behavioural and holding rooms relative to the larger building footprint is of course crucial to the specific needs for acoustic control. The following subsections discuss various architectural and services design aspects.

Wall and ceiling construction

A key design requirement linked to the operational and maintenance requirements of holding rooms is the ability to maintain air tightness.

Traditional lightweight wall systems such as plasterboard on steel studwork carry risk in forming airtight seals at all junctions, and design teams will often look to the use of insulated metal skin panels (e.g. Dagard, Bondor XFLAM or EPS core) continuously welded together to obtain suitable air pressurisation.

Airborne sound isolation typically suffers through this decision over typical drywall. The typical airborne weighted sound reduction index of 100mm metal skin panels in situ is approximately R_w 21dB, substantially less than that available using standard full height steel stud and plasterboard walls with polyester insulation. Whilst options for the designer would include employing two panels with airspace between (despite the cost in floor area that would require), it is important to determine what acoustic isolation provisions are required first.

The guidelines place a premium on the minimisation of intrusive noise, rather than aspects usually encountered in other medical facilities such as speech privacy or comfort.

Therefore, the acoustic design typically places the bulk of noise and vibration isolation controls at the perimeter of the animal house, in part relying on staff discipline and administrative controls to minimise noise from their activities within the facility.

Trafficable ceilings or floor/ceilings with low impact noise resistance are often necessary to service and inspect mechanical services specific to the Animal House and must be carefully reviewed against the airborne noise and vibration criteria.

Doors

Doors should employ soft closers to avoid slam under closure or minimise striking other objects if opened quickly. Threshold plates or sudden drops in floor level should be avoided to avoid equipment ‘bouncing’ over the obstacle.

Acoustic seals to doors may be prohibited depending on the level of bacterial control and cleaning regime required.

United States National Institutes of Health (2012) design requirements call for fibreglass reinforced polyester (FRP) doors to all rooms temporarily or permanently occupied by animals, and specifically bans the use of hollow metal doors.

All voids in framing are usually required to be filled/packed out with solid material; not for acoustic control, but to prevent establishment of pests.

Building services

There will be a substantial level of building services to animal house areas. Facility cleaning requirements will most likely place constraints on internal lining of ductwork; alternatively unit silencers at key locations with unlined ductwork could be employed.

Often, low level mechanical supply and exhaust systems are employed particularly with the likely use of specialist gases. In regards to the acoustic design this may have implications for the size of wall spacings and internal voids.

All services with rotating assemblies (e.g. VAV boxes, fans) should be relocated outside and as far from the rooms as practicable. Worn bearings over time have the potential to create high levels of ultrasonic noise with substantial risk to nearby sensitive areas well before noise and vibration are audible to humans and then triggering an investigation.

PHYSICAL SURVEY

Short term measurements of an existing and functional animal research facility were undertaken from a Monday to Wednesday in November 2011.

Measurement set up

A Type 1 RION NA-28 logger was setup inside animal holding room for un-attended measurement, see Figure 2. The microphone was located at approximately 1.5m above floor level on one of the unoccupied cage shelves. Care was taken to ensure the microphone was not impacted by vibration of the shelf unit. Checks for calibration were made before and after the set of measurements.

Figure 2: Rion NA-28 noise logger setup in Room 148

The logging unit was setup for recording in 5 minute summaries of third octave L_{AmaxF}, L_{AeqF} and discrete percentile values.

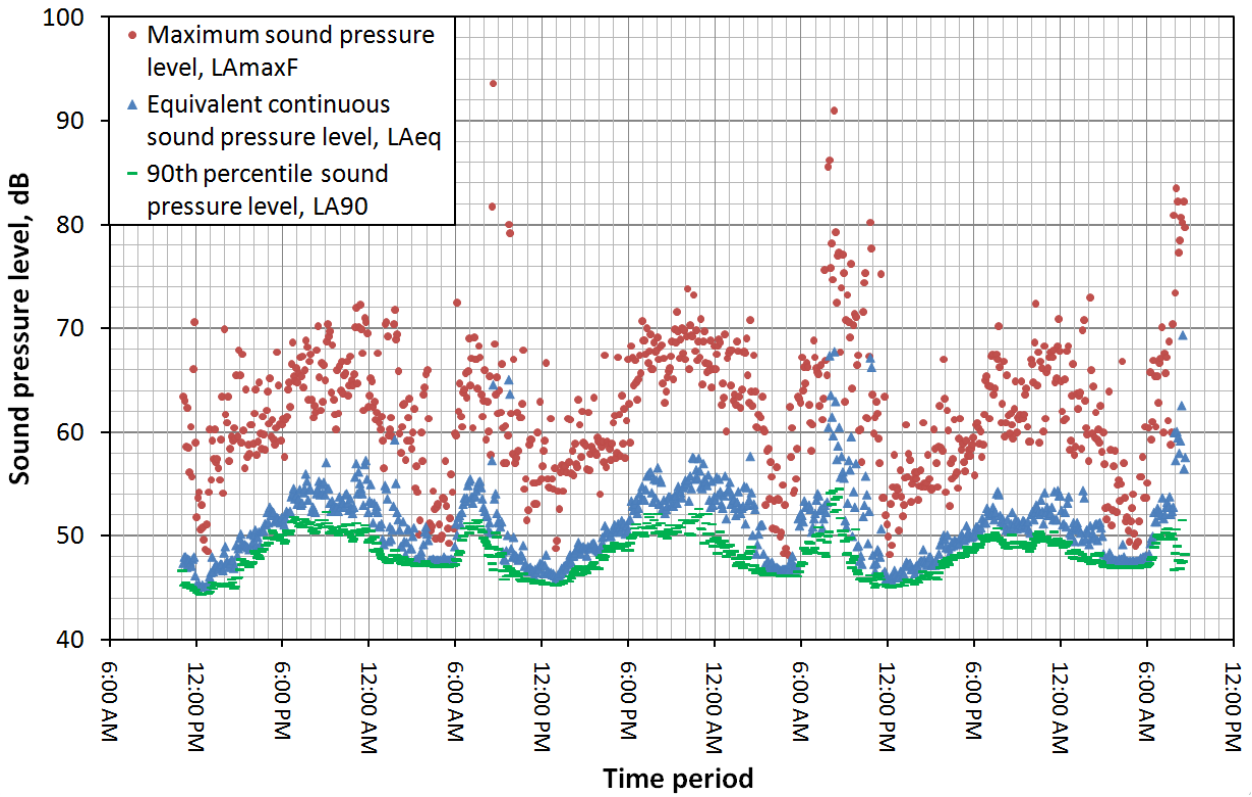

Figure 3: Measurement results in terms of five minute period L_{AmaxF}, L_{Aeq} and L_{A90}

Staff advised that the animal holding room is typical in the facility in terms of its use and fitout. Approximately a third of the tiered shelves were occupied with animal cages. Room 148 is at the end corridor of 5 other animal holding rooms.

Dominant background sound levels are due to building services and plant external to the room. External noise ingress is well controlled as the room is deep inside the building footplate, and not adjacent to any plant or lift cores.

Staff advised the room is typically only entered for daily cleaning activities and checks, which includes a spray washdown of the floor, using the hose partially visible on the left of Figure 1.

The door to this room is fitted with full perimeter rubber compression seals, with an external brush seal to the floor, and a sign to ensure it is closed properly. Seals were observed to be correctly installed and adjusted.

During the site visit it was noted that the majority of external noise ingress was from a cage-cleaning room located at the end of an adjacent corridor. Internally the major noise source was animal activity in the cages.

Staff described the logging period assessed as business as usual, except on the first day (inside the first twelve hours of measurements reported) where there was an incident of equipment failure in an adjacent room. No significant noise events were noted during this time period.

Logging results

A plot of continuous results is shown in Figure 3. As can be identified, noise levels follow a typical daily pattern of;

- A relatively short duration loud event between 8 and 10am, understood to be the results of cleaning activities including use of the hose.
- Consistent sound levels between 6pm and 2am.
- Marginally lower sound levels between 3am and 2pm (excluding cleaning activities).

The measurement results obtained are summarised as follows;

- Typical background noise levels (L_{A90}) being 42dB to 52dB throughout day periods.
- Maximum noise levels (L_{AmaxF}) range 50dB to 75dB through the day (excluding maintenance / cleaning).
- Daily maximum noise levels (L_{AmaxF}) up to 95dB, noted to be during the daily maintenance and cleaning of the room.

Informal comments from staff and participants included that;

- Staff were generally less concerned with background noise levels, and more concerned with infrequent peak noise with the potential to ‘startle’ animals.
- The laboratory manager noted that some other animal care facilities employed the use of low-level constant background music as a means of ‘pre-conditioning’ noise for the animals. Background music however is not preferred, as they don’t believe it to be effective.
- Anecdotally, there were issues at another facility where intense ultrasonic noise from worn mechanical unit fan bearings caused animals to cease breeding.
- Staff noted that the effect of loud noise / startled animals as affecting hormone levels, breeding and potentially test results. Staff indicated they were not aware of applicable benchmarks or otherwise objective noise level criteria.

Discussion

We note that with effective separation of Animal House sensitive areas from outside disturbances, internal conditions are dominated by the direct activity of people working in the vicinity and the increased activity of animals (vocalization, cage rattling, or banging) in response to those people.

Indeed, the lowest background sound levels within the facility were typically around midday.

This reinforces the view that effective design layout, operational planning and separation of research activities (from the research subjects) will be critical to achieving the acoustic criteria. It also implies that throughout operation of the facility, staff, visitors and operators of the facility alike will have ultimate responsibility in ensuring noise and vibration levels from their individual actions are not excessive.

CONCLUSIONS AND RECOMMENDATIONS

Acoustic design criteria for animal house facilities and the risks of adverse noise and vibration need to be tabled and discussed with key stakeholders and end users at the earliest opportunity.

Throughout operation of the animal house, staff, visitors and operators of the facility will have ultimate responsibility in ensuring noise and vibration levels from their individual actions are not excessive. Training of staff in regards to administrative controls will be needed to ensure sudden noise and vibration from equipment and activities is minimised.

Designers and consultants should visit existing facilities used by staff transitioning into the new facilities, to gain staff engagement and understanding of risks. This is because various acoustic treatments that might be employed as part of the design may be rendered ineffective if personnel using the facility do not employ suitable operational and maintenance requirements e.g. use of high pressure spray hoses, careless handling of materials and operating radios near sensitive areas at high volume.

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